STUDIES ON
SOME ASPECTS OF AGILITY APPRAISEMENT: EMPIRICAL RESEARCH AND CASE STUDIES IN INDIAN PERSPECTIVE

A Thesis Submitted in Fulfillment of the
Requirement for the Award of the Degree of

DOCTOR OF PHILOSOPHY

IN

MECHANICAL ENGINEERING

BY

SWAGATIKA MISHRA
ROLL NO. 510ME102

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008, ODISHA, INDIA
AUGUST 2013

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008, ODISHA, INDIA

CERTIFICATE OF APPROVAL

This is to certify that the thesis entitled **STUDIES ON SOME ASPECTS OF AGILITY APPRAISEMENT: EMPIRICAL RESEARCH AND CASE STUDIES IN INDIAN PERSPECTIVE** submitted by **Swagatika Mishra** has been carried out under our supervision in fulfillment of the requirement for the award of the degree of ***Doctor of Philosophy*** in ***Mechanical Engineering*** at **National Institute of Technology Rourkela** and this work has not been submitted to any university/institute before for any academic degree/diploma.

Dr. Saurav Datta
Assistant Professor

Prof. Siba Sankar Mahapatra
Professor

Department of Mechanical Engineering
National Institute of Technology, **Rourkela-769008**, **INDIA**

Acknowledgement

While bringing out this thesis to its final form, I came across a great number of individuals whose selfless dedication and contribution in various ways that helped me to execute this research work and therefore, they deserve special thanks. I am greatly indebted to them.

First and foremost, I would like to express my deep sense of gratitude and indebtedness to my supervisors **Dr. Saurav Datta**, Assistant Professor and **Prof. Siba Sankar Mahapatra**, Professor, Department of Mechanical Engineering, National Institute of Technology Rourkela, for their esteemed guidance, invaluable encouragement, moral support, free to act on my ideas and scholarly inputs from early stage of research work that instill confidence in me during the research work. Above all, their priceless and meticulous supervision at each and every phase of work has been the cradle of illumination for me. This thesis could not have been completed without their accordant suggestions, motivation, constant encouragement and crucial contribution, which have enriched value of my thesis. They had always been there to route me through all pros and cons.

Besides my supervisors, I would like to express my heartiest thankfulness to my Doctoral Scrutiny Committee (DSC) members: **Prof S. K. Patel**, Associate Professor, Department of Mechanical Engineering, **Prof. H. B. Sahu**, Associate Professor, Department of Mining Engineering and **Prof. K. K. Khatua**, Associate Professor, Department of Civil Engineering of our Institute for their kind co-operation and insightful comments throughout period of work which has been instrumental in the success of thesis.

I am also highly obliged to **Prof. S. K. Sarangi**, our Honorable Director, **Prof. S. Bhattacharya**, Dean (Academic Affairs), **Prof. K. P. Maity**, Head, Department of Mechanical Engineering, National Institute of Technology, Rourkela for their academic support and concern about requirements to carry out the research work at the Institute.

Special thanks with great pleasure to all the faculty and staff-members of the Mechanical Engineering Department for their vital information, kind and generous help during the progress of the work which forms the backbone of this work. Among them, **Mr. P. K. Pal** Technician (SG 1), CAD/CAM Lab of our department deserves special thanks for his kind cooperation in every administrative affair during the research work. Besides, this I will certainly carry the fond memories of the company of Research Scholars at CAD/CAM Lab, Department of Mechanical Engineering, NIT Rourkela, for their laudable help and cooperation to concentrate on my work all through.

I feel lucky to have **Chitrasen Samantra**, PhD Scholar (Production Specialization) of our Department for his continuous support and extended hands of cooperation. Our frequent discussion on various decision-making methodologies, advanced tools and techniques for meaningful data analysis as well as knowledge sharing added value to my thesis work. I got motivated by learning many things on fuzzy decision-making and related aspects in consultation with him. I do express my sincere thanks to him from the core of my heart.

I greatly appreciate and convey my heartfelt thanks to **Bikash Ranjan Debata**, **Shailesh Dewangan**, **Kumar Abhisek**, **Sanjita Jaipuria**, **Pallavi Banjare**, **Biranchi Narayan Panda**, **Pragyan Paramita Mohanty**, **Anoop Kumar Sahu** scholars associated with our department and all my well wishers for their support and co-operation that is difficult to express in words.

I greatly acknowledge **Mr. Goutam Mandal**, Ex. Manager (ERC), Jamshedpur Works, E.R.C. (JSR), **Tata Motors Ltd.**, Jamshedpur and **Mr. Prasenjit Das**, Section Engineer, **Kanchrapara Railway Workshop**, West Bengal, for their endless support and cooperation in course of conducting case studies.

I owe a lot to my parents, **Mr. Sukanta Mishra** (Father) and **Mrs. Chandrabali Mishra** (Mother), for their inseparable support and encouragement at every stage of my academic and personal life and yearned to see this achievement come true. They are the people who show me the joy of intellectual pursuit ever since I was a child. I thank them for sincerely bringing up me with care and love.

Words fail me to express my appreciation to my husband **Mr. Manas Ranjan Dash** for his understanding, patience and active cooperation throughout the course of my doctoral dissertation and I am highly thankful to him for bearing the inconvenience of stay away from me.

I also feel pleased to strongly acknowledge the support received from my brother **Biswajit** and sister **Sagarika** in every possible way to see the completion of this doctoral work. I am delighted to express my admiration to my parents-in-law for being supportive and caring.

I am grateful to Ministry of Human Resources Development, Government of India for the financial support provided during my tenure of stay at National Institute of Technology, Rourkela.

Finally, I would like to take this opportunity to express my sincere gratitude to all other individuals (not listed here) who have provided support and encouragement. I am grateful for their kindness.
Above all, I bow to the Devine power for granting me the wisdom, health and strength and led me all through.

SWAGATIKA MISHRA

Abstract

The thesis highlights decision-making problems in relation to agility evaluation as well as appraisement of agile enterprises followed be suppliers' selection in agile supply chain. Various aspects have been covered (i) Supply Chain Agility Appraisement and (ii) Appraisement of Agility in Mass Customized Product Manufacturing (iii) Organizational Agility and Benchmarking of Agile Enterprises, (iv) Interrelationship amongst Agile Capabilities/Enablers, (v) Identification of Agile Barriers etc.

Appraisement modules (appraisement index systems) have been proposed utilizing the concept of generalized fuzzy numbers, Interval-Valued Fuzzy Numbers (IVFNs) as well as grey numbers.

The study provides in-depth understanding on hierarchical interrelationship amongst various agility dimensions required to assess organizational as well as supply chain agility. Agility appraisement modules have been proposed to perform both in fuzzy as well as grey environment. Agility barriers have been identified as well. The outcome of the empirical research as well as case study conducted in two Indian industries (automotive and railway construction at eastern India) have been critically analyzed. The influence of decision-makers' risk bearing attitude over agility assessment and related decision-making has also been focused in this work. An efficient fuzzy embedded performance appraisement module has been proposed to facilitate suppliers' evaluation cum selection process in agile supply chain.

There exist a number of agility indices (metrics) that influence the extent of organizational agility. By evaluating these indices, appropriate ranking order of alternative agile enterprises can be determined. This being the basic fundamental of Multi-Criteria Decision Making (MCDM), it can effectively be explored towards benchmarking of agile enterprises. Evaluating the candidate agile alternatives and comparing across them, the best practices of the efficient organization can easily be identified and transferred to different organizations.

Indian manufacturing industries prefer to maintain status-quo and hardly go for changes (or transformation). However, today's market compulsion due to liberalization and globalization of demands that manufacturing firms must be agile enough to serve continuously changing unpredicted needs of the customers in an effective manner. The changes in terms of being agile are not easy enough due to several environmental, managerial and technical considerations. Analysis of drivers of agile manufacturing and their interaction with various aspects in integrative planning can be a valuable source of information to the decision-makers (DMs) for its successful implementation. In doing so, the managers can derive important insights into the problem and explore the said drivers efficiently to overcome those obstacles.

Agility evaluation problem can be viewed as a multi-criteria decision making (MCDM) problem involving qualitative as well as quantitative evaluation criterions. Quantitative criterions (attributes) can be tackled by traditional tools and approaches. Difficulty arises in dealing with subjective qualitative selection criterions. In this thesis, fuzzy logic (as well as grey theory) has been proposed to tackle decision-makers' subjective information/judgment in relation to agility appraisement and related decision-making

problems. Literature is rich enough in addressing various decision-modeling problems using generalized fuzzy numbers; therefore, fruitful incorporation of Interval-Valued Fuzzy Numbers theory and grey theory definitely added value (contribution) pursued in data analysis (empirical as well as case studies) in this thesis. Use of 'Fuzzy Degree of Similarity' concept in identifying weak (ill-performing) areas (called agile barriers) in an agile supply chain appears to be a unique contribution in this work.

Keywords: Agile Manufacturing (AM); Mass Customization (MC); Agile Supply Chain (ASC); Multi-Criteria Decision Making (MCDM)

Contents

Items	*Page Number*
Title Sheet	**i**
Certificate of Approval	**ii**
Acknowledgement	**iii-iv**
Abstract	**v-vi**
Contents	**vii-xii**
List of Tables Cited in the Text	**xiii-xiv**
List of Figures Cited in the Text	**xv**
CHAPTER 1	**<u>1-36</u>**
Research Background	
1.1 The Concept of Agility	2
1.2 State of Art Understanding	4
1.2.1 Conceptual Framework	4
1.2.2 Agile Supply Chain Management (ASCM)	9
1.2.3 Agility Evaluation	12
1.2.4 Agility Implementation	16
1.2.5 Agile Manufacturing System Design	19
1.2.6 Information System Agility	22
1.2.7 Leanness versus Agility: Leagility	24
1.3 Motivation and Objectives	29
1.4 Research Methodology	32
1.5 Organization of the Present Dissertation	34
CHAPTER 2	**<u>37-70</u>**
An Understanding of Interrelationship of Agile Enablers/Drivers in Indian Manufacturing Firms	
2.1 Interrelationship of Drivers for Agile Manufacturing: An Indian Experience	38
2.1.1 Overview	38
2.1.2 Introduction	38
2.1.3 Understanding of State of Art	40
2.1.4 An Overview of the ISM Approach	42
2.1.5 Results and Discussions	44
2.1.6 Concluding Remarks	50
2.2 Alignment of Dimensions towards Modeling Organizational Supply Chain Agility	52
2.2.1 Overview	52

2.2.2 Research Background 52
2.2.3 Understanding of State of Art 54
2.2.4 Factor Analysis 56
2.2.5 Case Study 57
2.2.6 Concluding Remarks 61

CHAPTER 3 **71-155**
Development of Agility Appraisement Modules in Industrial Supply Chain
3.1 Agility Appraisement in Fuzzy Context 72

3.1.1 Agility Appraisement using GTFNs Set 72
3.1.1.1 Overview 72
3.1.1.2 State of Art Understanding and Problem Formulation 72
3.1.1.3 Conceptual Model for Agility Measurement in Supply Chain 77
3.1.1.4 The Concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs) Set 77
3.1.1.5 The Concept of Comparing and Ranking of Trapezoidal Fuzzy Numbers 80
3.1.1.6 Procedural Framework 84
3.1.1.7 Concluding Remarks 88

3.1.2 Agility Appraisement using GIVFNs Set 94
3.1.2.1 Overview 94
3.1.2.2 Supply Chain Agility: Traditional versus Agile Supply Chain 94
3.1.2.3 Problem Statement 95
3.1.2.4 Introduction to Interval-Valued Trapezoidal Fuzzy Numbers 97
3.1.2.5 The Operation Rules of IV-Trapezoidal Fuzzy Numbers 97
3.1.2.6 The Distance between Two IV-Trapezoidal Fuzzy Numbers 98
3.1.2.7 Degree of Similarity Measurement Between Two IV-Fuzzy Numbers 99
3.1.2.8 Division Operator Ø for Interval-Valued Trapezoidal Fuzzy Numbers 104
3.1.2.9 Proposed Framework: Managerial Implementation 105
3.1.2.10 Concluding Remarks 111

3.1.3 Agility Appraisement in MC Product Manufacturing 113
3.1.3.1 Overview 113
3.1.3.2 Research Background 113
3.1.3.2.1 Mass Customization (MC) in Manufacturing/ Production Context 113
3.1.3.2.2 Measurement of Agility in MC Product Manufacturing 115
3.1.3.3 Design Adopted for Agility Evaluation of MC Product Manufacturing System 116
3.1.3.4 Problem Statement 117
3.1.3.5 Procedural Hierarchy 118
3.1.3.6 Managerial Implications 121
3.1.3.7 Concluding Remarks 121

3.2 Agility Appraisement in Grey Context 125
3.2.1 Overview 125
3.2.2 Background and Problem Statement 125

3.2.3 Theory of Grey Numbers: Mathematical Basis 127
3.2.4 Proposed Appraisement Platform 129
3.2.5 Concluding Remarks 133

3.3 Case Applications in Indian Perspective 137
3.3.1 Overview 137
3.3.2 Background on Fuzzy Mathematics: Generalized Triangular Fuzzy Numbers 137
3.3.3 Appraisement Modeling and Procedural Framework Adapted 143
3.3.4 Agility Appraisement in Automotive Sector 145
3.3.5 Agility Appraisement in Railway Construction 152
3.3.6 Managerial Implications 153
3.3.7 Concluding Remarks 154

CHAPTER 4 **156-201**
Organizational Agility, Benchmarking of Agile Systems and Analysis of Risk in Decision-Making
4.1 Appraisement of Organizational Agility 157
4.1.1 Overview 157
4.1.2 Agile Enterprise 157
4.1.3 Background and Problem Statement 159
4.1.4 Procedural Framework: Case Study 160
4.1.5 Concluding Remnarks 163

4.2 Grey Theory and Fuzzy-TOPSIS based Decision-Making Approaches for Agility Evaluation and Benchmarking of Mass-Customization Systems 166
4.2.1 Overview 166
4.2.2 Background 167
4.2.3 State of Art and Problem Statement 168
4.2.4 Agility Evaluation Platform 170
4.2.5 Grey and Fuzzy-TOPSIS based Appraisement Modeling 171
4.2.6 Results and Discussions 175
4.2.7 Concluding Remarks 185

4.3 Agility Evaluation in Fuzzy Context: Influence of Decision-Makers' Risk Bearing Attitude 186
4.3.1 Overview 186
4.3.2 State of Art and Problem Statement 188
4.3.3 Agility Evaluation Framework Adapted 189
4.3.4 Procedural Hierarchy 191
4.3.5 Case Study 193
4.3.6 Managerial Implications 200
4.3.7 Concluding Remarks 201

CHAPTER 5 **202-237**
Supplier Evaluation and Selection in Agile Supply Chain

5.1 Supplier Evaluation in ASC using Fuzzy Logic	203
5.1.1 Overview	203
5.1.2 Importance and Issues of Supplier Evaluation in Agile Supply Chain	203
5.1.3 State of Art and Problem Formulation	204
5.1.4 Proposed Fuzzy Based Supplier Evaluation Module	207
5.1.5 Empirical Research	208
5.1.6 Managerial Implications	209
5.1.7 Concluding Remarks	210
5.2 Supplier Selection in ASC using Fuzzy-MULTIMOORA	224
5.2.1 Overview	224
5.2.2 Problem Statement	224
5.2.3 The Crisp MULTIMOORA Method	225
5.2.4 MULTIMOORA METHOD based upon IV-Trapezoidal Fuzzy Numbers	227
5.2.5 Empirical Research	229
5.2.6 Concluding Remarks	232
CHAPTER 6 **Executive Summary and Conclusions**	**<u>238-243</u>**
Bibliography	**<u>244-274</u>**
List of Publications	**<u>275-277</u>**
Resume of SWAGATIKA MISHRA	**<u>278-279</u>**
APPENDICES	**<u>-1- to -101-</u>**

Table No.	*Tables Caption*	
Table 3.3	Ratings of agile criteria (Grade III) assigned by DMs using linguistic terms	-1-
Table 3.4	Weights of agile capabilities (Grade I) assigned by DMs using linguistic terms	-1-
Table 3.5	Weights of agile attributes (Grade II) assigned by DMs using linguistic terms	-2-
Table 3.6	Weights of agile criteria (Grade III) assigned by DMs using linguistic terms	-2-
Table 3.7	Aggregated decision-making cum evaluation matrix of agile criterions (Grade III)	-3-
Table 3.8	Aggregated decision-making cum evaluation matrix of agile attributes (Grade II)	-3-
Table 3.9	Aggregated decision-making cum evaluation matrix of agile capabilities (Grade I)	-4-
Table 3.14	Ratings of sub-criteria (Grade III) assigned by the DMs using linguistic terms	-5-
Table 3.15	Weights of main criteria (Grade I), sub-criteria (Grade II and Grade III) assigned by the DMs using linguistic terms	-6-
Table 3.16	Weights of sub-criteria (Grade II) assigned by the DMs using linguistic terms	-6-
Table 3.17	Weights of sub-criteria (Grade III) assigned by the DMs using linguistic terms	-6-
Table 3.18	Aggregated fuzzy ratings and aggregated fuzzy weights of sub-criteria (Grade III)	-8-
Table 3.19	Aggregated fuzzy ratings and aggregated fuzzy weights of sub-criteria (Grade II)	-9-
Table 3.20	Aggregated fuzzy ratings and aggregated fuzzy weights of main criteria (Grade II)	-9-
Table 3.24	Ratings of sub-criteria (Grade III) assigned by the DMs using linguistic terms	-10-
Table 3.25	Weights of sub-criteria (Grade III) assigned by the DMs using linguistic terms	-11-
Table 3.26	Weights of sub-criteria (Grade II) assigned by the DMs using linguistic terms	-12-
Table 3.27	Weights of main criteria (Grade I) assigned by the DMs using linguistic terms	-12-
Table 3.28	Average (aggregated) fuzzy ratings and average fuzzy weights of sub-criteria (Grade III)	-13-
Table 3.29	Average (aggregated) fuzzy ratings and average fuzzy weights of sub-criteria (Grade II)	-14-

Table 3.30	Average (aggregated) fuzzy ratings and average fuzzy weights of main criteria (Grade I)	-14-
Table 3.35	Appropriateness rating of agile criterions given by the decision-makers	-15-
Table 3.36	Priority weights of agile criterions given by the decision-makers	-16-
Table 3.37	Priority weights of agile attributes given by the decision-makers	-17-
Table 3.38	Priority weights of agile capabilities/ enablers given by the decision-makers	-17-
Table 3.39	Aggregated grey priority weight and appropriateness rating of agile criterions	-18-
Table 3.40	Aggregated grey priority weight and computed appropriateness rating of agile attributes	-19-
Table 3.41	Aggregated grey priority weight and computed appropriateness rating of agile capabilities	-19-
Table 3.45	Assignment of criteria weight as given by the evaluation team	-20-
Table 3.46	Assignment of attribute weight as given by the evaluation team	-22-
Table 3.47	Assignment of priority weight corresponding to individual agile capabilities as given by the evaluation team	-22-
Table 3.48	Appropriateness rating (linguistic judgment) against agile criterions (3rd level indices) as given by the decision-makers	-23-
Table 3.49	Aggregated weight and appropriateness rating of agile criterions	-31-
Table 3.50	Aggregated weight and computed appropriateness rating of agile attributes	-33-
Table 3.51	Aggregated weight and computed appropriateness rating of agile capabilities	-33-
Table 3.53	Appropriateness rating (linguistic judgment) against agile 2nd level attributes as given by the decision-makers (DMs)	-34-
Table 3.54	Aggregated fuzzy weight and appropriateness rating against each 2nd level agile attributes	-34-
Table 3.55	Aggregated fuzzy weight and computed appropriateness rating against each 1st level agile capabilities	-35-
Table 4.3	Weights of agile providers (Grade II) assigned by the DMs using linguistic terms	-36-
Table 4.4	Weights of agile attributes (Grade III) assigned by the DMs using linguistic terms	-36-
Table 4.5	Ratings of agile attributes (Grade III) assigned by the DMs using linguistic terms	-37-
Table 4.6	Aggregated fuzzy rating and priority weights for agile attributes (Grade III)	-38-
Table 4.7	Computed fuzzy rating and aggregated fuzzy priority weights for agile providers (Grade II)	-38-
Table 4.29	Membership functions for linguistic Rating set S (β=0.5)	-39-
Table 4.30	Membership functions for linguistic weighting set W (β=0.5)	-39-
Table 4.31	Criteria ratings assigned by experts (Level 3 indices)	-40-
Table 4.32	Criteria weights as suggested by experts (for Level 3 Index)	-42-
Table 4.33	Attribute weights suggested by experts (for Level 2 Index)	-44-
Table 4.34	Weights of agile capabilities as suggested by experts (Level 1 Index)	-46-
Table 4.35	Ranking value for four set of decision-makers **(β=0.5169)**	-48-
Table 4.36	Membership functions for linguistic rating set S (β=0.2)	-49-
Table 4.37	Membership functions for linguistic weighting set W (β=0.2)	-49-
Table 4.38	Criteria rating assigned by experts (for Level 3 Index)	-50-
Table 4.39	Criteria weights as suggested by experts (for Level 3 Index)	-52-
Table 4.40	Attribute weights as suggested by experts (for Level 2 Index)	-54-
Table 4.41	Weights of agile capabilities as suggested by experts (Level 1 Index)	-56-
Table 4.42	Ranking value for decision makers **(β= 0.2068)**	-58-
Table 4.43	Membership functions for linguistic rating set S (β=0.9)	-59-
Table 4.44	Membership functions for linguistic Weighting set W (β=0.9)	-59-
Table 4.45	Criteria rating assigned by experts (for Level 3 index)	-60-
Table 4.46	Criteria weights as suggested by experts (for Level 3 Index)	-62-
Table 4.47	Attribute weights as suggested by experts (for Level 2 Index)	-64-
Table 4.48	Weights of agile capabilities as suggested by experts (for Level 1 Index)	-66-
Table 4.49	Ranking value for decision makers **(β= 0.9304)**	-68-

Table 5.3	Priority weights of sub-criteria (3rd Level) assigned by the DMs using linguistic terms	-69-
Table 5.4	Priority weights of main criteria (2nd Level) assigned by the DMs using linguistic terms	-71-
Table 5.5	Rating of sub-criteria (3rd Level) assigned by the DMs using linguistic terms	-72-
Table 5.6	Aggregated ratings and weights of sub-criteria (3rd Level) in terms of fuzzy numbers	-74-
Table 5.7	Computed ratings and aggregated weights of main-criteria (2nd Level) in terms of fuzzy numbers	-77-
Table 5.11	Priority weights of 1st level indices assigned by the decision-makers	-78-
Table 5.12	Priority weights of 2nd level sub-indices assigned by the decision-makers	-78-
Table 5.13	Performance Ratings of 2nd level sub-indices assigned by the decision-makers **(Alternative 1)**	-81-
Table 5.14	Performance ratings of 2nd level sub-indices assigned by the decision-makers **(Alternative 2)**	-85-
Table 5.15	Performance ratings of 2nd level sub-indices assigned by the decision-makers **(Alternative 3)**	-89-
Table 5.16	Performance ratings and weights of 2nd Level sub-indices assigned by the decision-makers **(Alternative 1)**	-93-
Table 5.17	Performance ratings and weights of 2nd level sub-indices assigned by the decision-makers **(Alternative 2)**	-96-
Table 5.18	Performance ratings and weights of 2nd level sub-indices assigned by the decision-makers **(Alternative 3)**	-99-

List of Tables Cited in the Text

Table No.	*Table Caption*	*Page Number*
Table 2.1	Structural self-interaction matrix (SSIM)	46
Table 2.2	Initial reachability matrix	46
Table 2.3	Final reachability matrix	47
Table 2.4	Partition of reachability matrix: 1st iteration	47
Table 2.5	Partition of reachability matrix: 2nd iteration	48
Table 2.6	Partition of reachability matrix: 3rd iteration	48
Table 2.7	Partition of reachability matrix: 4th iteration	48
Table 2.8	Questionnaire: Perception of industry personnel: Assignment of performance rating against 3rd level evaluation indices	63
Table 2.9	Factor loading scores	66
Table 2.10	Dimensions of agility	68
Table 2.11	Percentage of variation explained by factor analysis	69
Table 3.1	Agility appraisement framework for integrated supply chain	90
Table 3.2	Definitions of linguistic variables for criteria ratings and weights (A 9-member linguistic terms set)	91
Table 3.10	Ranking order of agile capabilities at Grade I by comparing corresponding (FPII)	92
Table 3.11	Ranking order of agile attributes at Grade II (under each capability) by comparing corresponding (FPII)	92
Table 3.12	Ranking order of agile criterions at Grade III by computing corresponding utility score	93
Table 3.13	Definitions of linguistic variables for criteria ratings and weights (A 9-member linguistic terms set)	111
Table 3.21	Ranking order of agile criterions (based on fuzzy Degree of Similarity concept)	112
Table 3.22	Agility evaluation index system of MC product manufacturing (Yang and Li, 2002)	123
Table 3.23	Definitions of linguistic variables for criteria ratings and priority weights (A 9-member linguistic terms set)	124
Table 3.31	Definitions of linguistic variables to identify agility level ratings (A 9-member linguistic terms set)	124
Table 3.32	Supply chain agility appraisement framework (Radfar et al., 2011)	134
Table 3.33	The scale of attribute weights	135
Table 3.34	The scale of attribute ratings	135
Table 3.42	Computation of GPII and corresponding agile criteria ranking	136
Table 3.43	The proposed agility appraisement model (3-level index system hierarchy)	147
Table 3.44	Linguistic scale towards estimating priority weight and assignment of performance rating	149
Table 3.52	Ranking of agile criterions exploring the concept of 'maximizing set and minimizing set' in fuzzy set theory	150
Table 3.56	Ranking of agile attributes based on the concept of 'overall utility degree'	155
Table 3.57	Ranking of agile attributes based on the concept of 'fuzzy degree of similarity'	155
Table 4.1	Organizational agility appraisement model (adapted from Shih and Lin, 2002)	163
Table 4.2	Definitions of linguistic variables for criteria ratings (A-9 member generalized trapezoidal fuzzy numbers set)	164
Table 4.8	Ranking score of agile attributes (Grade III)	164
Table 4.9	Ranking score of agile providers (Grade II)	165

Table 4.10	The scale of attribute weights w	174
Table 4.11	The scale of attribute ratings G	174
Table 4.12	Attribute weights for five criteria	175
Table 4.13	Attribute ratings for alternatives	176
Table 4.14	Grey decision-matrix	176
Table 4.15	Grey normalized decision-matrix	177
Table 4.16	Grey weighted normalized decision matrix	177
Table 4.17	Linguistic variables for importance weight of each criterion	179
Table 4.18	Linguistic variables for appropriateness ratings	179
Table 4.19	Importance weight of criterions	180
Table 4.20	Attribute ratings for alternatives	181
Table 4.21	Fuzzy decision-matrix and corresponding fuzzy weights	181
Table 4.22	Normalized fuzzy decision-matrix	183
Table 4.23	Weighted normalized fuzzy decision-matrix	183
Table 4.24	Distance between A_i (i=1, 2, 3, 4) and A^* with respect to each criterion	184
Table 4.25	Distance between A_i (i=1, 2, 3, 4) and A^- with respect to each criterion	184
Table 4.26	Computation of d_i^*, d_i^- and CC_i	184
Table 4.27	Computed values of $P(A_i \le A_{max})$ and CC_i	184
Table 4.28	Proposed agility appraisement model	194
Table 5.1	General hierarchy criteria (GHC) for supplier evaluation in ASC	211
Table 5.2	Definitions of linguistic variables for criteria ratings and priority weights (A-9 member linguistic term set)	214
Table 5.8	3rd level sub-criteria ranking based on utility score	215
Table 5.9	3rd level sub-criteria ranking based on fuzzy similarity measure *(Degree of Similarity Concept)*	219
Table 5.10	A 9-member linguistic term set and their corresponding interval-valued fuzzy numbers	234
Table 5.19	Performance ratings and weights of 1st level indices assigned by the decision-makers **(Alternative 1)**	234
Table 5.20	Performance ratings and weights of 1st level indices assigned by the decision-makers **(Alternative 2)**	235
Table 5.21	Performance ratings and weights of 1st level indices assigned by the decision-makers **(Alternative 3)**	235
Table 5.22	Weighted normalized decision-making matrix	236
Table 5.23	Evaluation of alternatives as computed by *Ratio System*	237
Table 5.24	Evaluation of alternatives as computed by *Reference Point Approach*	237
Table 5.25	Evaluation of alternatives as computed by *The Full Multiplicative Form* of MULTIMOORA method	237
Table 5.26	Performance ranking order of agile suppliers according to dominance theory and fuzzy-MULTIMOORA	237

List of Figures Cited in the Text

Figure No.	*Figure Caption*	*Page Number*
Fig. 1.1	Classification of literature	5
Fig. 1.2	Distribution of the work carried out on various aspects of agility	29
Fig. 1.3	Focus areas (coverage) of the present work	36
Fig. 2.1	ISM based model for understanding of drivers in agile manufacturing	49
Fig. 2.2	Driving power and Dependence diagram	50
Fig. 2.3	Average perception of agile entities	70
Fig. 3.1	Generalized trapezoidal fuzzy numbers	78
Fig. 3.2	Interval-valued trapezoidal fuzzy numbers	96
Fig. 3.3	Agility measurement appraisement framework	122
Fig. 3.4	The concept of a grey system	127
Fig. 3.5	A fuzzy number $\tilde{n}$	138
Fig. 3.6	A triangular fuzzy number $\tilde{A}$	139
Fig. 4.1	A triangular fuzzy number	178
Fig. 4.2	Comparison of grey method and Fuzzy-TOPSIS for four agile alternatives	185

CHAPTER 1

RESEARCH

BACKGROUND

1.1 The Concept of Agility

As we are approaching towards 21st century, success and survival of manufacturing sectors/production units are becoming very difficult to ensure (Shari and Zhang, 1999). This fact is rooted in the emergence of a new business era that has 'change' as one of its major characteristics. Enterprises deal with changes in different aspects such as change in customer demand, technological advancements and unstable business environment (Shahraki et al., 2011). This critical situation has forced towards undertaking a major revision and reengineering in the contemporary business priorities, strategic vision, and examining viability of traditional models and methodologies developed so far. The emphasis is now being paid on adaptability to change in the volatile business environment and a proactive way of approaching to marketplace and customer needs through newly evolved cooperation methods such as Virtual Enterprise (VE). The emerging paradigm is denoted as Agile Manufacturing (AM), which is conceptualized as a step forward in generation of new means for better performance and success of business and in practice is a strategic approach to manufacturing considering the new market conditions as well as opportunities. Responding to unpredictable market changes and taking competitive advantage of them through systematic strategic utilization of managerial and manufacturing methods and tools, is the pivotal concepts of agile manufacturing.

Competitive advantage depends upon a dynamic capability to compete successfully in a frequent, challenging and often, unpredictable marketplace. Now-a-days, successful survival by taking competitive advantage through product price alone has no longer been a viable strategy for most of the manufacturing firms. Firms need to succeed in markets where a range of non-price advantages are frequently expected by customers. Order-winning criteria include rate of innovation, fitness for purpose, volume flexibility, variety, extreme customization and above all, rapid responsiveness (Meredith and Francis, 2000). Gradual increase of global and local competition exhibits organizations that are unable to respond proactively to these consumer needs, they are unlikely to survive. Exploration of the principles and practices of agile enterprise seems to offer a stable candidate solution.

Agile manufacturing is a new concept that aims at improving the competitiveness of manufacturing firms. Manufacturing firms based on AM are mainly characterized by customers-supplier integrated process for product design, manufacturing, marketing, and support services. This requires prompt and efficient decision-making at functional knowledge levels, stable unit costs, flexible manufacturing system, easy access to integrated data, adaptation and exploration of information technology, and modular production facilities. Agile manufacturing requires enriching of the customer, co-operating with competitors, organizing to manage change, uncertainty and complexity, and leveraging people and information (Gunasekaran, 1999).

Manufacturing industries, even those running in relatively stable conditions with considerable market share are facing rapid and often unanticipated changes in their business environment. Each company must respond in a specific and different way to the changing circumstances by deploying its own agile characteristics. Agility in manufacturing may be achieved through the implementation and integration of appropriate practices which provide the required abilities for a company to respond properly to changes (Sharifi and Zhang, 2001).

Tough and competitive market has led to increase attention being paid to customer satisfaction of which timely and customized products/services are the key concerns. As the product life cycle becomes shortened, high product quality becomes evident for successful survival. Markets become highly diversified and spread over the globe and continuous and unexpected change becomes the key success factors. The need for a method of rapidly and cost-effectively developing products, production facilities and supporting software including design, process planning and shop floor control system has led to the concept of agile manufacturing (Gunasekaran, 1998).

Agile manufacturing can be defined as the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets driven by customer-designed products and services. Speed and responsiveness are two basic characteristics of agility. According to (Gunasekaran, 1998), the key enablers of agile manufacturing include: (i) virtual enterprise formation tools/metrics; (ii) physically distributed manufacturing architecture and teams; (iii) rapid partnership formation tools/metrics; (iv) concurrent engineering; (v) integrated product/production/business information system; (vi) rapid prototyping tools; and (vii) electronic commerce.

In short, the agility as a 21st century paradigm is an organization's capability to explore opportunities based on the current market-change. It is the efficacy of an organization to face and withstand in highly turbulent as well as volatile marketplace continuously pressurized by unpredictable change in customers' needs. Substantial volume of research has been found well documented in literature in relation to this advanced market winning strategy. The next section (Section 1.2) provides glimpses of past research that has been carried out by pioneers in this particular area with an effort to identify and visualize the research gap clearly.

1.2 State of Art Understanding

In order to understand the state of art of the previous research and thereby, identifying and conceptualizing the directions of the present work, an exhaustive literature review has been conducted. Around 140 research articles collected from journals of international/national repute, conference proceedings, books etc. have been thoroughly surveyed. Within this scope, literature has been categorized into seven different thrust areas on which pioneers made in-depth focus (Fig. 1.1). These are as follows:

1. Conceptual framework
2. Agile supply chain management
3. Agility evaluation
4. Agility implementation
5. Agile manufacturing system design
6. Information system agility, and
7. Leanness versus agility: Leagility

The research outcome on aforementioned seven areas as documented in literature have been critically reviewed and summarized below.

1.2.1 Conceptual Framework

In today's rapidly changing and highly competitive business environment, the need to quickly adapt and respond to market opportunities while controlling manufacturing costs has become critical to survival (Young 1995; Richard et al., 1997). Katayama and Bennett (1999) dealt with three concepts of concern to manufacturing management; agile manufacturing, adaptable production and lean production. These were described and compared within the context of the modern competitive situation in Japan. A survey of Japanese firms was described where the concepts were explored through a number of questions concerned with strategy, action programmes and performance measures.

Many companies responded to the change in economic conditions through a modification of their production operations and by changing their cost structure. The results suggested that companies were trying to realize their cost adaptability through agility enhancement activities.

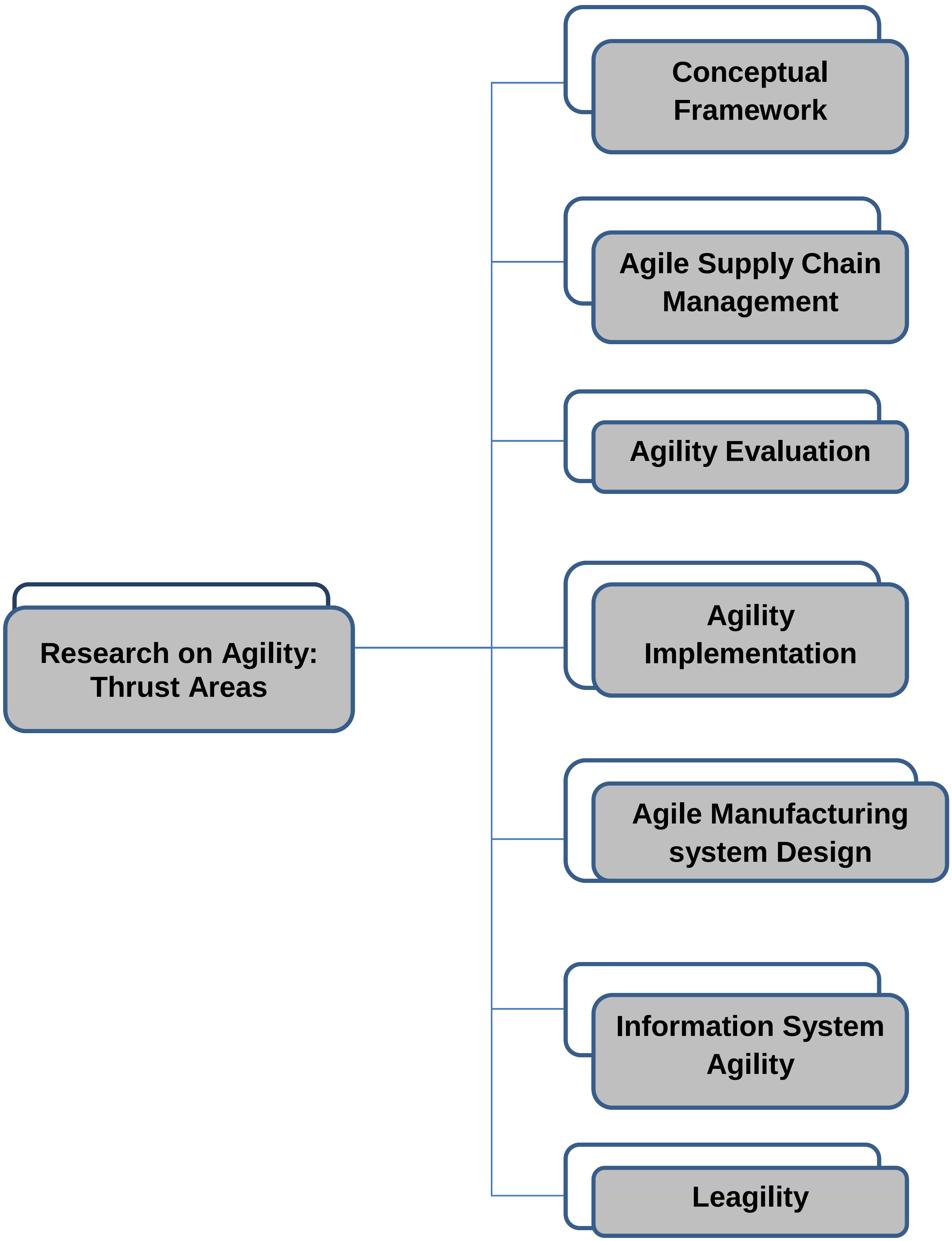

Fig. 1.1: Classification of literature

Shari and Zhang (1999) discussed the concepts and the development of a methodology to achieve agility based on them. Gunasekaran (1999) attempted to review the literature available on Agile Manufacturing (AM) with the objective to: (i) identify key strategies and techniques of AM, (ii) suggest some future research directions and (iii) develop a framework for the development of agile manufacturing systems along four key dimensions which include strategies, technologies, systems and people.

Yusuf et al. (1999) identified the drivers of agility and discussed the portfolio of competitive advantages that emerged over time as a result of the changing requirements of manufacturing. The need to achieve the competitive advantages of manufacturing in synergy and without trade-offs was reported as fundamental to the agile paradigm. Furthermore, this paper reviewed the meaning of agility from different perspectives and suggested a comprehensive definition which could be adopted as a working definition by practitioners. Meredith and Francis (2000) discussed various issues on agility based upon preliminary findings of the Agile Manufacturing Research Group (AMRG). Through introduction of the agile wheel reference model (AWRM), they identified the specific policies and practices that support agility. Sharifi and Zhang (2001) developed a methodology for achieving agility in manufacturing organizations. The methodology was applied in two manufacturing companies and data collected from the applications were used to validate the methodology. This paper provided a brief summary of the methodology and details of implementation and validation in the two case examples. Practices were proposed to support the achievement of agility in the two organizations.

Maskell (2001) examined the development of agile manufacturing and explored the key success factors such as customer prosperity, people and information, co-operation within and between firms, and fitting a company for change. The study highlighted the need for agile companies to adequately address their customers' fast-changing and focused requirements. To achieve this goal the staff must be highly educated and trained and significantly empowered within the constraints of a clear vision and delineated company principles and goals. The ability to effect change rapidly, highly flexible management structures and comprehensive methods of introducing change must be required. Gunasekaran and Yusuf (2002) attempted to examine the scope, definitions and strategies of AM. In addition, a framework was presented as a basis for understanding the major strategies and relevant technologies of AM. Ren et al. (2003) identified the dominant and critical agile attributes and their effects on competitive priority. A method of artificial neural network (ANN) having capability of a multi-layer perceptron with back propagation algorithm was proposed. The proposed network configured could detect, classify and estimate the extent of effects of agile attributes on competitive capabilities.

Li et al. (2003) reported that Real Agile Manufacturing (RAM) emphasizes on surviving and prospering in the competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets. RAM was shown to be based upon these fundamental principles like multiple winners (manufacturers, suppliers, customers), integration (recourses, methods, technologies, departments or organizations), and Information Technology (IT). Agarwal et al. (2006) presented a framework which encapsulated the market sensitiveness, process integration, information driver and flexibility measures of supply chain performance. The paper explored the relationship among lead-time, cost, quality, and service level and the leanness and agility of a case supply chain in fast moving consumer goods business. The paper analyzed the effect of market winning criteria and market qualifying criteria on the three types of supply chains such as lean, agile and leagile.

Kim et al. (2006) suggested a framework for designing the agile and interoperable Virtual Enterprises (VEs). This modeling framework could be used for business managers or business domain experts to build an agile and interoperable VE quickly and systematically with insights. It also supported a coherent enterprise modeling in which various stakeholders having their own aspects and methodology such as an IT manager and a business manager could communicate effectively. Narasimhan et al. (2006b) discussed leanness and agility in two ways: - (1) as manufacturing paradigms and (2) as performance capabilities. This study attempted to determine whether lean and agile forms occur with any degree of regularity in manufacturing plants. The results confirmed the existence of homogeneous groups that resembled lean and agile performing plants and identified important differences pertaining to their constituent performance dimensions. The results indicated that while the pursuit of agility might presume leanness, pursuit of leanness might not presume agility. Sherehiy et al. (2007) conducted a critical review and identified the global characteristics of agility which could be applied to all aspects of enterprise viz. flexibility, responsiveness, speed, culture of change, integration and low complexity, high quality and customized products, and mobilization of core competencies. Ramesh and Devadasan (2007) contributed a comprehensive model to identify the criteria for attaining agility and suggested a procedure to successfully implement it in manufacturing arena. They enunciated the exhaustive integration of management and technology-oriented AM criteria and their implementation feasibilities.

Daniel et al. (2007) analyzed agile manufacturing practices in Spain and studied whether it was a critical factor for success in different industries. The results showed that the integrated use of agile manufacturing practices promoted manufacturing competitive strength, leading to better operational, market and financial performance in turbulent environments. Managers should consider the integrated implementation of agile manufacturing practices in order to develop manufacturing strength and outperform competitors in turbulent business environments. Kumar et al. (2008) analyzed various enablers of agile manufacturing system and developed interrelationships using Interpretive Structural Modeling (ISM). These enablers were classified with different driving powers and dependencies. This paper might help the manufacturers and suppliers for rapid product development by identifying the enablers as drivers and dependence and integrating the entire systems. Chan and Thong (2009) addressed action plans to be undertaken to overcome the challenge to agile methodologies acceptance. The authors provided a critical review of the extant literature on the acceptance of traditional System Development Methodologies (SDMs) and agile methodologies and developed a conceptual framework for agile methodologies acceptance based on a knowledge management perspective. Bottani (2009) attempted to link competitive bases, agile attributes and agile enablers, aimed at identifying the most appropriate enablers to be implemented by companies starting from competitive characteristics of the related market. The approach was based on the quality function deployment (QFD) methodology which was successfully adopted in the new product development field. The whole procedure exploited fuzzy logic to translate linguistics judgments required for relationships and correlations matrices into numerical values. An illustrative example grounded on data available in literature was proposed and discussed to show the application of the tool developed.

Hallgren and Olhager (2009) investigated internal and external factors to drive the choice of lean and agile operations capabilities and their respective impact on operational performance levels. It was reported that lean and agile manufacturing differ in terms of drivers and outcomes. The choice of a cost-leadership strategy fully mediates the impact of the competitive intensity of industry as a driver of lean manufacturing, while agile manufacturing is directly affected by both internal and external drivers i.e. a differentiation strategy as well as the competitive intensity of industry. Agile manufacturing is found to be negatively associated with a cost-leadership strategy emphasizing the difference between lean and agile manufacturing. The major differences in performance outcomes are related to cost and flexibility such that lean manufacturing has a significant impact on cost performance (whereas agile manufacturing has not) and that agile manufacturing has a stronger relationship with volume as well as product mix flexibility than does lean manufacturing.

Zhang (2010) presented a case-based investigation of the practical details of the three basic types of agility strategies such as quick, responsive, and proactive. A cross-case analysis found that the choice of agility strategies is related to the nature of markets and competition, the characteristics of products (life cycles and degrees of maturity), and market positions of individual companies. Inmana et al. (2010) theorized and tested a structural model incorporating agile manufacturing as the focal construct. The model included the primary components of Just-in-Time or JIT (JIT-purchasing and JIT-production) as antecedents and operational performance and firm performance as consequences to agile manufacturing. Using data collected from production and operations managers working for large U.S. manufacturers, the model was assessed following a structural equation modeling methodology. The results indicated that JIT-purchasing had a direct positive relationship with agile manufacturing while the positive relationship between JIT- production and agile manufacturing was mediated by JIT-purchasing. Bottani (2010) attempted to improve the existing knowledge on agility and aimed at investigating both the profile of agile companies and the enablers practically adopted by companies to achieve agility. The empirical investigation was performed on a sample of about 190 companies, about 65% of which were small and medium enterprises (SMEs). Results of the analysis provided a detailed investigation of the agile paradigm and outcomes suggested new taxonomies for agile attributes and enablers and in particular provided evidence of attributes and enablers that appeared as most relevant in embracing an agile strategy. Yaghoubi and Dahmardeh (2010) studied the effective factors on organizational agility including drivers, capabilities and enablers of the agility. The paper presented some conceptions of agility at the beginning and a brief history of it. Then, drivers, capabilities and 26 enablers introduced with imparting different theories and models. It was expected that this research would be able to accelerate the organizations getting success and helping the future researchers.

1.2.2 Agile Supply Chain Management (ASCM)

Today's' global competitive marketplace is characterized by changing customer and technological requirement. To face such a market instability and turbulence, enterprises need to emphasize on cost and quality advantage. Business efficiency and effectiveness can be achieved through reassessing internal business operations such as purchasing, warehousing, material management and distribution. Speed, quality, and flexibility need to be effectively emphasized towards responding to the customer's ever changing unpredictable needs. To become more responsive to the needs of customer and market require more than speed, it also requires a high-level maneuverability that has come to be the term agility. Agility in supply chain is one of the solutions to achieve competitive advantage as it provides many opportunities for reducing operating cost and improving customer service and satisfaction (Anatan, 2006).

Supply chain agility enables an organization to react quickly and more effectively to marketplace volatility and other uncertainties, thereby allowing the firm to establish a superior competitive position (Aziz and Zailani, 2011).

In short, agility of a supply chain represents the extent of adaptation to key elements of supply chain agility. The key success factors for supply chain agility include customer enrichment ahead of competitors, achieving mass customization at the cost of mass production, mastering change and uncertainty through routinely adaptable structures, and leveraging the impact of people across enterprises through information technology. Agility is the fundamental characteristic of a supply chain needed for survival in turbulent and volatile markets due to shortened product life cycles and uncertainties in environmental conditions (Agarwal et al., 2007; Luo et al., 2009).

Gunasekaran et al. (2008) analyzed both AM and Supply Chain Management (SCM) with the objective of developing a framework for responsive supply chain (RSC). The proposed framework could be employed as a competitive strategy in a networked economy in which customized products/services are produced with virtual organizations and exchanged using e-commerce. Hoek et al. (2001) presented an attempt to establish an audit of agility in the supply chain. The audit was used in an empirical investigation of agile capabilities in Europe. Using existing streams of supply chain research as building blocks, a preliminary framework was introduced for creating an agile supply chain. Based on a survey of agile efforts in the UK and the Benelux, the agile capabilities of companies were assessed and approaches to outscore the benchmark were suggested. Yusuf et al. (2004) reviewed emerging patterns in supply chain integration. It also explored the relationship between the emerging patterns and attainment of competitive objectives. The most important task of the agile supply chain management (ASCM) is to reconfigure a supply chain based on the customers' requirement. Without more sophisticated cooperation and dynamic formation in an agile supply chain, it cannot be achieved for mass customization, rapid response and high quality services. Because of its great potential in supporting cooperation for the supply chain management, agent technology can carry out the cooperative work by inter-operation across networked human, organization and machines at the abstractive level in a computational system. In this context, Song et al. (2007) used the agent technology to support modeling and coordinating of supply chain management.

Wadhwa et al. (2007) presented the modeling framework based on analytical network process (ANP) to accommodate the complex and tacit interrelationship among factors affecting enterprise agility. The modeling framework formed a three-level network with the goal of attaining agility from the perspective of market, product, and customer as the actors. The goal depended on sub strategies that addressed the characteristics of the three actors. Each of these sub strategies further depended on manufacturing, logistic, sourcing, and information technology (IT) flexibility elements of the enterprise supply chain (SC). The research highlighted that, under different environmental conditions, enterprises require synergy among appropriate supply chain flexibilities for practicing agility. In this research, the ANP modeling software tool Super Decisions ™ was used for relative prioritization of the supply chain flexibilities.

Agarwal et al. (2007) used interpretive structural modeling to understand interrelationships of the variables that influence supply chain agility. Baker (2008) examined the design and operation of distribution centers within agile supply chains by means of case studies emphasizing how individual business units design and operate distribution centers to provide a rapid response to their markets. Kisperska-Moron and Swierczek (2009) explored the main agile capabilities of Polish companies in supply chains. The variables, which had an impact on the inter-organizational agility in the supply chains, were identified. Having performed a factor analysis in a space of the variables, the constructs were extracted and employed as classification criteria in a cluster analysis. The results of the study showed that the examined companies could be grouped into different classes having distinct characteristics. Huang et al. (2009) proposed the generic label correcting (GLC) algorithm incorporated with the decision rules to solve supply chain modeling problems. The rough set theory was applied to reduce the complexity of data space and to induct decision rules. This approach was agile because by combining various operators and comparators, different types of paths in the reduced networks could be solved with one algorithm.

Luo et al. (2009) developed a model to overcome the information-processing difficulties inherent in screening a large number of potential suppliers in the early stages of the selection process. Based on radial basis function artificial neural network (RBF-ANN), the model enabled potential suppliers to be assessed against multiple criteria using both quantitative and qualitative measures. Its efficacy was illustrated using empirical data from the Chinese electrical appliance and equipment manufacturing industries. Wu and Barnes (2010) attempted to advance Dempster–Shafer and optimisation theories in order to use it in partner selection decision-making in agile supply chains. Aziz and Zailani (2011) addressed the issues of supply chain agility as promising area of study that had the potential to provide significant practical benefits to the firms. Specifically, this conceptual paper addressed the determinants and outcomes expected from supply chain agility in the context of Electrical and Electronics (E&E) firms in Malaysia. Wu and Barnes (2011) highlighted various decision-making models and approaches for partner selection in agile supply chains. Costantino et al. (2012) addressed the configuration problem of Manufacturing Supply Chains (MSC) with reference to the supply planning issue. The authors presented a technique for the strategic management of the chain addressing supply planning and allowing the improvement of the MSC agility in terms of ability in reconfiguration to meet performance. Yusuf et al. (2012) examined agility in the UK North Sea upstream oil and gas industry to identify the most important attributes of supply chain agility. This work provided new insights into characteristics most relevant within the oil and gas industry. Sukati et al. (2012) investigated the relationship between organizational practices and supply chain agility. Vinodh et al. (2013) applied fuzzy VIKOR (VlseKriterijumskaOptimizacija I KompromisnoResenje in Serbian, meaning multi-criteria optimization and compromise solution) for concept selection in an agile environment.

Pan and Nagi (2013) considered a supply chain network design problem in an agile manufacturing scenario with multiple echelons and multiple periods under a situation where multiple customers had heavy demands. Decisions in the supply chain design problem included selection of one or more companies in each echelon, production, inventory, and transportation. The authors formulated the problem integrating all decisions to minimize the total operational costs including fixed alliance costs between two companies, production, raw material holding, finished products holding, and transportation costs under production and transportation capacity limits. A *Lagrangian* heuristic was proposed in this paper.

1.2.3 Agility Evaluation

Agility is the ability of an organization to adapt to change and also to seize opportunities that become available due to change. While there has been much work and discussion of what agility is and how firms can become agile there is little work at measuring the agility of a firm. Measurement is necessary for the strategic planning of determining how much agility an organization currently posses, determining how much is needed, and then for assessing the gap and formulating a strategy for closing any perceived weaknesses (Arteta and Giachetti, 2004).

Yang and Li (2002) established an Mass-Customized (MC) product manufacturing agility evaluation index system through studying MC enterprise's organization management agility evaluation; MC products design agility evaluation, and MC manufacture agility evaluation. The multi-grade fuzzy assessment method was used to evaluate agility of a case organization. Tsourveloudis and Valavanis (2002) proposed a knowledge-based framework as a candidate solution for the measurement and assessment of manufacturing agility. Given an enterprise, in order to calculate its overall agility, a set of quantitatively defined agility parameters was proposed and grouped into production, market, people and information infrastructures. The combined, resulting, measure incorporated the individual and grouped infrastructure agility parameters and their variations into unique calculated value of the overall agility. The necessary expertise used to quantitatively determine and measure individual agility parameters was represented via fuzzy logic terminology.

The measurement of agility seemed difficult to measure since it must be measured in the context of a change (Arteta and Giachetti, 2004). Consequently, most current agility measurement approaches were found backward looking. A different and novel approach is to use complexity as a surrogate measure for agility. The hypothesis supporting this substitution is that a less complex enterprise in terms of systems and processes is easier to change and consequently more agile. To test this idea, Arteta and Giachetti (2004) presented a model and measurement approach for measuring complexity. The model used Petri Nets to find the state space probabilities needed for the complexity measure. Wanyu et al. (2005) discussed a method for evaluating the agility of dynamic alliance based on certainty factor inference and fuzzy logic inference. Using this method, the randomness and fuzziness of evaluation indexes could be expressed and managed entirely. This method might play positive role in seeking alliance partner for the leader of an alliance, and in evaluating the agility of an enterprise to improve itself.

Lin et al. (2006a) developed the concept of the absolute agility index, a unique and unprecedented attempt in agility measurement, using fuzzy logic to address the ambiguity in agility evaluation. In another reporting, Lin et al. (2006b) highlighted a fuzzy agility index (FAI) based on agility providers using fuzzy logic. The FAI comprised attribute' ratings and corresponding weights, and was aggregated by a fuzzy weighted average. To illustrate the efficacy of the method, this study also evaluated the supply chain agility of a Taiwanese company. Jain et al. (2008) proposed an approach based on Fuzzy Association Rule Mining to support the decision-makers (DMs) by enhancing the flexibility in making decisions for evaluating agility with both tangibles and intangibles attributes/criteria such as Flexibility, Profitability, Quality, Innovativeness, Pro-activity, Speed of response, Cost and Robustness. Also, by checking the fuzzy classification rules, the goal of knowledge acquisition could be achieved in a framework in which evaluation of agility could be established without constraints, and consequently checked and compared in several details. Chandna (Kharbanda) (2008) also presented a fuzzy logic- knowledge-based framework for the assessment of manufacturing agility. The combined measure incorporated certain operational parameters, their variations, and their effect on the value of agility.

Qumer and Henderson-Sellers (2008) developed an analytical framework called 4-DAT in course of comparing agile and traditional methods. Wang (2009) proposed an MC manufacturing agility evaluation approach based on concepts of TOPSIS through analyzing the agility of organization management, product design, processing manufacture, partnership formation capability and integration of information system. The 2-tuple fuzzy linguistic computing manner to transform the heterogeneous information assessed by multiple experts into an identical decision domain was inherent in the proposed method. Dimitropoulos (2009) introduced an index for measuring the capability of a company to timely and profitably exploit windows of upcoming commercial opportunity and a model for calculating the long-term cost of software in agile production environments. The evaluation focused on the effects of the production infrastructure on the strategic and tactical ability of the company. Through the introduced index and software cost model, the impact of software on the agility of automatic production systems was explained, along with the benefits from reconfigurable production control software build upon open standards.

Ganguly et al. (2009) devoted to developing a framework and quantifying the notion of agility. The authors proposed three techniques and associated metrics for determining enterprise agility. Lastly, the paper presented a case study related to Apple'ss digital media to demonstrate the utility of the methodology and associated metrics. Vinodh et al. (2010a) reported a research carried out to assess the agility level of an organization using a multi-grade fuzzy approach. During this research, an agility index measurement model containing twenty criteria incorporated with the multi-grade fuzzy approach was designed. Subsequently, the data gathered from a manufacturing company was substituted in this model and the proposals for enhancing the agility level of this company were derived. The usage of the model contributed in this paper would indicate the actions required to enhance an organization's agility level. In another reporting, Vinodh et al. (2010b) proposed a model called total agile design system (TADS). The implementation study conducted to examine this model in a traditional manufacturing company was briefly appraised. A scoring model was used for measuring agility before and after implementation of TADS. The implementation study revealed the improvement of agility by 10%. This improvement was appreciable in traditional manufacturing organization where only the mass production-based practices were only currently practiced.

Jassbi et al. (2010) developed an approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for evaluating agility in supply chain considering agility capabilities such as Flexibility, Competency, Cost, Responsiveness and Quickness. This evaluation helped the managers to perform gap analysis between existent agility level and the desired one and also provided more informative and reliable information for decision making. Finally, the proposed model was applied to a leading car manufacturing company in Iran to prove the applicability of the model. Seyedhoseini et al. (2010) developed an approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for measurement of agility in Supply Chain in order to inject different and complicated agility capabilities (i.e. flexibility, competency, cost, responsiveness and quickness) to the model in an ambiguous environment. Shahraki et al. (2011) examined the necessity of adapting agility as a vital and inevitable activity in global economic system. In this paper details of the approach and a framework of fuzzy agility evaluation were asserted. An example was also used to illustrate the approach developed.

Yauch (2011) attempted to construct a quantitative and objective metric for agility performance that assessed agility as a performance outcome capturing both organizational success and environmental turbulence and applicable to manufacturing organizations of all types. The agility performance metric was developed by creating a theoretical model and then made it operating through literature review, case studies, and pilot survey data. It was subsequently refined based on input from an expert panel and survey responses. Yaghoubi et al. (2011) focused on the concept, importance and necessity of accessing agility and associated reasons. The authors assessed agility with the Goldman methodology based on fuzzy approach. In this respect, several questionnaires were distributed among the top managers of Saipa Yadak car co., Iran. Finally, after precise and through analyses, the sub- criteria were recognized based on the fuzzy approach and the possible obstacles for reaching the agility level and different recommendations were suggested. Motadel et al. (2011) identified supply chain agility indicators in the automotive industry of Tehran. Also the model of supply chain agility in SAZEGOSTAR SAIPA Co. was obtained with regression. Radfar et al. (2011) presented a model for evaluating the agility in supply chain of two dominant telecommunication companies in Iran. To avoid inherent ambiguities caused by linguistic methods, this evaluation model explored Fuzzy Inference System (FIS) efficiently.

Vinodh et al. (2011) performed agility assessment through a case example of an Indian electric automotive car manufacturing organization using a scoring approach and validated using an effective multi-grade fuzzy method. Vinodh et al. (2012) conducted an extensive research towards assessing agility of the manufacturing organization using a scoring approach. This paper presented a thirty criteria agility assessment model to measure agility degree and to identify the agile characteristics of organization. Thus, weak factors were identified and future proposals were suggested so as to enhance organizational agility extent. The authors presented a case study in an Indian pump manufacturing organization.

1.2.4 Agility Implementation

Agile manufacturing enables an organization to produce a variety of products within a short period of time in a cost-effective manner. With the competition of the markets getting much more severe, it is becoming imperative to construct a highly efficient agile manufacturing system conforming to customer requirement in products' research and development, manufacture, sales and service. Besides manufacturing management, data deeply utilization, e-commerce and production optimization is also necessary for manufacturing enterprises (Liu et al., 2004).

Cho and Jung (1996) highlighted key concepts like standard for the exchange of products (STEP), concurrent engineering, virtual manufacturing, component-based hierarchical shop floor control system information and communication infrastructure etc. as enabling technologies related to implementation of agile manufacturing in Korea. Gunasekaran (1998) presented a conceptual framework for the development and implementation of an agile manufacturing system. This framework considered customization and system integration with the help of business process redesign, legal issues, concurrent engineering, computer-integrated manufacturing, cost management, total quality management and information technology. Cheng et al. (1998) presented an approach towards implementing agile design and manufacturing concepts. The approach was based on the integration of Artificial Intelligence (AI) and Internet technologies with the conventional design and manufacturing techniques. The paper concluded on the potential benefits and the future applications of AI and Internet based agile manufacturing technology in industry. Robertson and Jones (1999) described the application of agility strategy, originally developed for manufacturing industry, in a telecommunications context. Lyu (1999) discussed the key elements of the CALS (continuous acquisition and life-cycle support) strategy and derived the necessary tactics to tackle the application of the strategy towards effective implement an agile management system. Sharp et al. (1999) proposed a conceptual model developed to identify where UK's best practice companies were in their quest to become agile. In support of this, a questionnaire was developed and completed by best practitioners of manufacturing to assess the model and establish whether they were making progress to becoming agile manufacturing organizations.

CALS strategy which originated in the American military in 1985 is widely embraced by many countries to build a digitized product life-cycle supporting environment for their industries. Zhang and Sharifi (2000) discussed a methodology to assist manufacturing companies to achieve and implement agility. Industrial questionnaire surveys and case studies were carried out to support and validate the said methodology. Frayret et al. (2001) presented a strategic framework for designing and operating agile networked manufacturing systems. This framework allowed collaborative planning, controlling and managing day-to-day operations and contingencies in a dynamic environment. The NetMan (Neither Market nor Hierarchy) (Powell, 1990) organizational and collaboration strategy consisted of a dynamic business method to organize and operate manufacturing activities through the configuration, activation and operation of a distributed network of inter-dependent and responsible manufacturing centers. The concepts underlying this strategic framework as well as the technical implications of such an approach were illustrated, using a detailed case study inspired by a motor coach industrial partner.

Mass customization relates to the ability to provide individually designed products and services to every customer through high process flexibility and integration. Mass customization has been identified as a competitive strategy by an increasing number of companies.

Silveira et al. (2001) surveyed the literature on mass customization. Enablers to mass customization and their impact on the development of production systems were discussed in length. Approaches to implementing mass customization were compiled and classified. Gunasekaran et al. (2002) presented a case study conducted on agile manufacturing in the GECMarconi Aerospace (GECMAe) company. GECMAe manufactures pumping systems, pneumatic systems, electro-mechanical actuators and sub-systems, and fuel handling and metering equipment for ground applications and for bulk fuel distribution. The study provided the reader with an insight into the company and its agility level. An agility audit questionnaire was used for assessing the agility level of the company. GECMAe's agile manufacturing experience was reported including a list of recommendations for improving its competitiveness. Elkinsa et al. (2004) discussed two simple decision models that provided initial insights and industry perspective into the business case for investment in agile manufacturing systems. The models were applied to study the hypothetical decision of whether to invest in a dedicated, agile, or flexible manufacturing system for engine and transmission parts machining. These decision models were a first step toward developing practical business case tools that helped industry to assess the value while implementing agile manufacturing systems.

Liu et al. (2004) analyzed the main feature of customer-driven manufacturing system and pointed out that there were four crucial subsystems viz. integrated manufacturing subsystem, data warehouse subsystem, quick responding subsystem and e-sales subsystem, catering to the requirements of various customers in time. This paper also provided the realization case of customer-driven agile manufacturing system in Baosteel, China. Poolton et al. (2008) examined the application of the principles of agile manufacturing to marketing strategy, planning and management in the context of small and medium-sized enterprises (SMEs). The study used the case study method to test the development and deployment of agile marketing by applying the marketing techniques normally practiced only by larger companies within the ‘hard’ and ‘soft’ constraints imposed by one small company’s managerial attitudes, corporate resources and time horizons.

Sidky et al. (2007) presented the agile adoption framework and the innovative approach used to implement it. The framework consisted of two components such as an agile measurement index and a four-stage process that was made to guide and assists the agile adoption efforts of organizations. More specifically, the Sidky Agile Measurement Index (SAMI) encompassed various agile levels that were used to identify the agile potential of projects and organizations.

Zhang (2007) proposed a framework for the agility implementation and described the development and analysis of a numerical taxonomy of agility strategies using the proposed framework. The taxonomy was developed with cluster analysis based on the relative importance attached to seven agility capabilities by a number of U.K. manufacturing companies. Three distinct clusters of strategy groups were observed across the industry studied such as Quick, Responsive and Proactive Players. It was reported that Quick Players are oriented towards a strong customer focus and quickness. They do not emphasize flexibility and responsiveness to changes and they give low priority to proactiveness and partnership. Responsive Players are preoccupied with flexibility and responsiveness to changes. They do not emphasize proactiveness and partnerships and they attach low importance to quickness. Proactive Players are characterized by high priorities on proactiveness and customer focus, high values attached to all capabilities, and high importance given to partnerships. The underlying dimensions of agile capabilities along which the three strategy groups differ were investigated based on factor analysis and canonical discriminant analysis.

Ifandoudas and Chapman (2009) documented an action research (AR) project aimed at identifying the practical steps needed to become an agile manufacturer through a combination of the theory of constraints (TOC) and resource- based view (RBV) approaches in a small-to-medium enterprise (SME) in the Australian manufacturing sector. Petersen and Wohlin (2009) conducted empirical studies for identifying a number of issues and advantages of incremental and agile methods. Xu (2009) studied the actuality analysis of the medium and small-scale manufacturing industry production mode in his country while implementing agile manufacturing strategy.

Vinodh et al. (2010) highlighted Total Agile Design System (TADS), a model, analogous to the technology integrated agile product development cycle. As reported by the authors, concept selection is an important phase of TADS which is a multi-criteria decision-making (MCDM) problem. Selection of the best concept from agile perspective gains vital importance. The concepts of fuzzy logic were integrated with Analytical Network Process (ANP) in order to overcome the vagueness and uncertainty associated with opinions of the decision-makers. Fuzzy ANP was utilized in this study to enable the selection of best concept. The case study was carried out in an Indian traditional manufacturing organization. The results of the validation indicated that fuzzy ANP was found an effective approach for selecting best concept thereby improving agility of product development process. Tseng and Lin (2011) suggested an agility development method for dealing with the interface and alignment issues among the agility drivers, capabilities and providers using the Quality Function Deployment (QFD) relationship matrix and fuzzy logic. A fuzzy agility index (FAI) for an enterprise composed of agility capability ratings and a total relation-weight with agility drivers was developed to measure the agility level of an enterprise. This report also described how this robust approach was applied to develop agility in a Taiwanese information technology (IT) product and service enterprise. Laanti et al. (2011) reported that agile methods were rapidly replacing traditional methods by providing evidence from a large-scale agile transformation within Nokia. Garbie (2011) proposed a conceptual model to measure the agility level of the petroleum companies in Oman based on existing technologies, level of qualifying human resources, production strategies, and organization management systems. Several case studies were presented to demonstrate the proposed issues and technique through an agility questionnaire which was used for assessing the agility level of these companies. These studies provide the readers with an insight into the companies and their agility levels. Carlson and Turner (2013) reviewed selected non software agile case studies for lessons that were applicable to implementing agile methods to transform the aircraft systems integration process.

1.2.5 Agile Manufacturing System Design

Lee (1998) considered agile manufacturing in the early design of components and manufacturing systems. A design for agility rule was formulated, proved, and substantiated by numerical results. The design rule reduced manufacturing lead times in consecutive changes of product models. Along with changes of product models, machines were relocated considering the overall costs of material handling and reconfiguration. A machine relocation problem was mathematically formulated and solved with a solution procedure developed in this paper. Kusiak and He (1998) attempted to simplify scheduling of manufacturing systems through appropriate design of products and manufacturing systems. An attempt has been made to generate rules that allowed designing products and systems for easy scheduling. The implementation of the rules was also discussed. Gunasekaran (1999) reported on design and implementation aspects of agile manufacturing systems. Suitable strategies were discussed for the development of agile manufacturing. These strategies mainly focused on virtual enterprise, supply chain management and concurrent engineering. Zhang et al. (1999) discussed the object-oriented modeling for cell control system. This paper defined manufacturing entity object (MEO) as reusable building block of modeling and addressed the structure of manufacturing entity object. MEO modeling scheme facilitated the process of modeling.

To address the challenges of a rapidly changing manufacturing market, a new type of manufacturing system with characteristics of Reconfigurability, reusability and scalability, an agile manufacturing system (AMS) has to be developed. Reconfigurability is an essential feature of AMS. Such a system can use basic building blocks both hardware and software which can be reconfigured quickly and reliably. A fundamental early step in the reconfiguring process for an agile manufacturing system is to develop a model that adequately describes the proposed system, in order to be able to study and evaluate the impact of the reconfiguring decision on the system performance, before its construction. Therefore, the rapid modeling and reusable modeling capabilities are demanded (Chan and Zhang, 2001).

In this context, Chan and Zhang (2001) proposed an Object and Knowledge-based Interval Timed Petri-Net (OKITPN) approach which provided an object-oriented and modular method of modeling manufacturing activities. It included knowledge, interval time, modular and communication attributes. The features of object-oriented modeling allowed the AMS to be modeled with the properties of classes and objects and made the concept of software IC possible for rapid modeling of complex AMSs. Once all of the Interval Timed Petri-Net (ITPN) objects were well defined the developers need to consider only the interfaces and operations relating to the ITPN objects. In order to demonstrate the capability of the proposed OKITPN, the authors attempted to model rapidly AMSs that were reconfigured according to requirements.

Li et al. (2002) summarized the general situation of research on agile fixture design and the achievements and deficiencies in the field of case-based fixture design. Furthermore, a whole case-based agile fixture design model was presented in which three modules were introduced including the evaluation of the similarity of fixture planning, conflict arbitration and the modification of an agile fixture case. The three modules could be used to solve a problem where experience and design results cannot be re-used in the process of fixture design. BüyüKözkan et al. (2004) pointed out the synergistic impact of new product development (NPD) and concurrent engineering (CE) (which can be called together CNPD) and to survey their methods and tools in association with the AM.

Meza' et al. (1997) attempted to develop optimization algorithms and software tools that enabled automated design thereby allowing for agile manufacturing. This report described the development of a common set of optimization tools using object-oriented programming techniques that could be applied to these types of problems. The authors gave examples of several applications that are representative of design problems including an inverse scattering problem, a vibration isolation problem, a system identification problem for the correlation of finite element models with test data and the control of a chemical vapor deposition reactor furnace. Because the function evaluations are computationally expensive, we emphasize algorithms that can be adapted to parallel computers. Carlsona and Yao (2008) carried out investigations in simulating an agile as well as synchronized manufacturing system (furniture production systems). The simulation developed represented an existing production system. It generated expected outputs under conditions of operation variability, queue lengths (buffers) and batch changeover (set-up) times over a range of three uniform and feasible batch sizes. Thus, the real-time status and location of components and subassemblies consigned to a specific production batch was essential for maintaining and improving quality and utilization of personnel, space, material and other resources.

Bhat (2008) provided fundamental insight into how manufacturing systems should be designed and reconfigured over time in order to cope with different agile manufacturing factors. To achieve this objective the author developed three approaches and integrated into one simulation-based model. The first approach was used to model different agile manufacturing environments. The second approach was proposed to define various ways in which manufacturing systems could be designed and reconfigured (i.e., design/reconfiguration strategies). The third comprised the cost and objective functions used to measure system performance when different design/reconfiguration strategies were used in different agile manufacturing environments. It was concluded that it is important in certain manufacturing environments to focus on reconfiguration in short periods of time, even at the expense of higher reconfiguration costs.

The complexity of a production system is caused by two factors: by a time-independent poor design that causes low efficiency (system design) and by a time dependent reduction of system performance due to system deterioration or to market or technology changes (system dynamics). To optimize the efficiency and changeability of a production system both factors must be considered (Matt, 2010). Starting from complexity theory, Matt (2010) presented a procedure that helped not only to design production systems with low or zero time-independent complexity (focus: flexibility and efficiency) but also to prevent the unpredictable influences of the time-dependent combinatorial complexity by transforming it into a periodic review and adaptation of the system’s volume and variant capabilities (focus: agility).

Grimheden (2013) presented a study of the integration of agile methods into mechatronics design education as performed at KTH Royal Institute of Technology, Sweden. The chosen method, Scrum and the context of the studied capstone course were presented. It was shown that it was possible and favorable to integrate Scrum in a mechatronics capstone course and that this could enhance student preparation for a future career as mechatronics designers or product developers. It was also shown that this had the capability to prepare the students with a larger flexibility to handle the increased complexity in mechatronics product development and thereby enabling the project teams to deliver results faster more reliably and with higher quality.

1.2.6 Information System Agility

Manufacturing companies are facing rapid and unanticipated changes in their business environment. Agile manufacturing (AM) is a manufacturing paradigm that focuses on smaller scale, modular production facilities, and agile operations capable of dealing with turbulent and changing environments. Virtual enterprise (VE) and information technology (IT) are to important enablers of agility implementation.

Information systems are regarded as enablers and facilitators of the concept of agile manufacturing. Adrian et al. (2002) addressed with the definition of an appropriate set of information technology/information systems (IT/IS) proficiency characteristics. Moreover, the work studied the evolution of IT/IS in manufacturing and the importance of information systems to support a series of attributes widely recognized in the literature of agile manufacturing. The results enabled the opportunity to start building guidelines for the identification of information systems requirements to support agility. Lee et al. (2004) introduced a dynamic data interchange scheme which attempted to exchange the data automatically as well as enabled the filtering of valuable data between traditional relational database model and case-based reasoning knowledge repository. The significance of this paper was concerned with the intelligent data exchange within a hybrid database system, embracing the empirical data to help agile manufacturing enterprises make critical decisions.

Cao and Dowlatshahi (2005) explored the impact of the alignment between VE and IT on business performance in an AM setting. It was also established that the alignment between VE and IT had a positive impact on business performance. Further, it was shown that the impact of the alignment between VE and IT on business performance was more significant than the impact of VE and IT on business performance individually.

Agile Software Development and the breed of Agile Methodologies (XP, SCRUM, DSDM, etc.) have gained popularity since 2001. Primarily founded as methodologies for software projects executed at a single location, Agile Methodologies have started showing promising results in multi-site projects too with many adopters and practitioners across the globe. It is therefore desirable to have an analytical tool to evaluate current agile software development methods in practice. In this context, Qumer and Henderson-Sellers (2008) proposed a 4-Dimensional Analytical Tool (4-DAT) for researchers and practitioners for the purpose of analysis and comparison of agile methods. 4-DAT would facilitate the examination of agile methods from four perspectives or dimensions: method scope characterization, agility characterization, agile values (agile manifesto) characterization and software process characterization. The tool was intended for use by software practitioners to compare and analyze agile methods. A report that was generated with the help of 4-DAT could be used for decision making regarding the adoption of an appropriate agile method. Bavani (2009) explored experience in executing outsourced product development and testing engagements using distributed agile practices. This paper presented critical success factors that need to be considered while implementing agile software development and testing across distributed teams.

Dimitropoulos (2009) introduced an index for measuring the ability of a company to timely and profitably exploit windows of upcoming commercial opportunity and a model for calculating the long-term cost of software in agile production environments. The evaluation focused on the effects of the production infrastructure on the strategic and tactical ability of the company. Through the introduced index and software cost model the impact of software on the agility of automatic production systems was explained along with the benefits from reconfigurable production control software build upon open standards. Misra et al. (2009) advanced the state-of-the-art of the research in agile software development (ASD) by conducting a survey-based ex-post-facto study for identifying factors from the perspective of the ASD practitioners that would influence the success of projects that adopt ASD practices. The important success factors that were found such as customer satisfaction, customer collaboration, customer commitment, decision time, corporate culture, control, personal characteristics, societal culture, and training and learning.

Wan and Wang (2010) discussed agile software process improvement in P company (P company being a multi-business company with main business in telecommunications services in Hong Kong) with their description of process management in current level and analysis of problems, design the P Company success factors model in organizational culture, systems, products, customers, markets, leadership, technology and other key dimensions, which was verified through questionnaire in P company. The authors used applications knowledge creation theory to analyze the open source software community with successful application of the typical agile software method, proposed principles of knowledge creation in open source software community: Self-organizing, Code sharing, Adaptation, Usability, Sustention, Talent, Interaction, Collaboration, Happiness and Democracy.

Hoda et al. (2012) used Grounded Theory as a qualitative research method to study forty agile practitioners across sixteen software organizations in New Zealand and India and explored how these agile teams made themselves self-organized. The authors demonstrated the application of Grounded Theory to Software Engineering. In doing so, the authors presented (a) a detailed description of the Grounded Theory methodology in general and its application in research in particular; (b) discussed the major challenges they encountered while performing Grounded Theory's various activities and their strategies for overcoming these challenges and (c) presented a sample of our data and results to illustrate the artifacts and outcomes of Grounded Theory research.

Wang et al. (2012) focused on 'leagile' software development. It was shown that lean could be applied in agile processes in different manners for different purposes. Lean concepts, principles and practices were most often used for continuous agile process improvement, with the most recent introduction being the *KANBAN* approach, introducing a continuous, flow-based substitute to time-boxed agile processes.

1.2.7 Leanness versus Agility: Leagility

In this era of globalization modern manufacturing enterprises are continuously facing tough market competitions. The remarkable industrial growth in past few decades has completely revolutionized their traditional manufacturing strategies giving emergence to the modern concepts of lean, agile, and nowadays, leagile manufacturing. These new strategies enable the enterprises to survive in the turbulent environment of violent competitions laid down by their competitors. The requirement of faster delivery within due date, the ability of being flexible to satisfy fluctuating market demand have been the prime motivations that has provoked manufacturing enterprises to look for the available best alternatives and implement it in their daily manufacturing practices. This led to the development of a new concept of 'leagility', which is an integration of lean and agile principles. Agile manufacturing is adopted where demand is volatile and lean manufacturing is adopted where there is a stable demand. However, in some situations it is advisable to utilize a different paradigm on either side of the material flow de-coupling point to enable a total supply chain strategy. This approach is termed as leagile paradigm (Mason-Jones, 2000a, b).

Recent advancements have shown that leagile principle has immense potential to counteract the existing complexity of the market scenario. Therefore, leagile principles are, nowadays, attracting modern manufacturing enterprises; researchers as well as management practitioners are aiming to find its potential benefits almost in all industrial sectors throughout the globe.

Lean manufacturing focuses on cost reduction by eliminating non-value added activities so that several advantages can be obtained such as minimization/elimination of waste, increased business opportunities and to gain competitive advantage. Lean manufacturing is generally adopted where there is a stable demand and to ensure a level schedule. The term 'lean manufacturing', which first appeared in 1990s (Womack, 1990, Holweg, 2007) when it was used to refer to the elimination of waste in the production process, has been announced as the production system of the 21st century. Historically, the concept of lean manufacturing was originated with Toyota Production Systems (TPS); and Toyota had increasingly become known for its effectiveness in implementing Just-In-Time (JIT) manufacturing systems. Lean manufacturing is called 'lean' as it uses less or the minimum, of everything required to produce a product or perform a service. Lean operations eliminate seven tedious wastes, namely overproduction, over processing, motion, waiting, transportation, defects, and inventory.

On the contrary, agile manufacturing is the ability to respond and create new windows of opportunity in a turbulent market environment driven by the individualization of customers' requirements cost effectively, rapidly and continuously. Agile manufacturing is essentially the utilization of market knowledge and virtual corporation to exploit profitable opportunities in a volatile marketplace (Power et al., 2001; Katayama and Bennett, 1999; Christopher, 2000).

Agile manufacturing is used to represent the ability of a producer of goods and services to thrive in the face of continuous change. These changes can occur in markets, in technologies, in business relationships and in all facets of the business enterprise. On the contrary, for the lean manufacturing the emphasis is on cost-cutting. The requirement for organizations to become more flexible and responsive to customers' expectations led to the concept of agile manufacturing as a differentiation from the lean organization.

Leagility is the combination of the lean and agile paradigms within a supply chain strategy by proper positioning the 'decoupling point'. A leagile system has the characteristics of both lean and agile parts, acting together in order to exploit market opportunities in a cost-efficient manner. The system defined as leagile could be an entire supply chain or a single manufacturing plant with individual lean and agile sub-groups containing a decoupling point, which separates the lean and agile portions of the system. The decoupling point is the point in the material flow streams to which the customer's order penetrates (Mason-Jones et al., 2000a, b; Prince and Kay, 2003). It is the point where order driven and the forecast driven activities meet. A decoupling point within a factory enables lean and agile practices to complement each other at the operational level to improve overall performance and profitability of the factory. The most important reason behind combining these two concepts is to take advantages of both in a single unit; because, there is always a need for responding to volatile demand downstream and providing level scheduling upstream from the marketplace (Hoek et al., 2001).

Naylor et al. (1999) believed that agile and lean manufacturing can be treated as complement to each other in the right operational conditions and should not be viewed as competitive, rather as mutually supportive. Agility is dynamic and context specific, aggressively change embracing and growth oriented (Goldman et al., 1995). Agile manufacturing promises not only improved manufacturing performance but also the support of future business strategies designed to improve the way in which an enterprise competes in the market place. On a strategic level agile manufacturing is seemed very attractive for its potential to cope up with future uncertainty and the prospect of producing a wide range of highly customized products at mass production prices. Therefore, these two concepts can be combined within successfully designed and operated supply chains where agile manufacturing concepts are applied to the part of the supply chain under the greatest pressure to operate in an environment of fluctuating demand in terms of volume and variety. Lean concepts can then be applied to the rest of the supply chain to create and encourage level demand necessary to achieve the cost benefits associated with this production strategy. The innovation being sought is the application of lean and agile concepts at different stages of the same manufacturing process route so that the benefits of both strategies can be maximized.

Naylor et al. (1999) compared lean and agile paradigm highlighting the similarities and differences as agile manufacturing is best suited to satisfy a fluctuating demand and lean manufacturing requires a level schedule. They combined both the paradigm within a total supply chain strategy particularly considering market knowledge and positioning of the decoupling point. Mason-Jones et al. (2000a) integrated lean production and agile supply in the total supply chain and supplemented by information enrichment which required evaluation of the total performance metric and development of a route map. Adopting such an approach to supply chain re-engineering ensured that customer service levels were improved at the same time lead times and costs were greatly reduced. Mason-Jones et al. (2000b) classified supply chain design and operations according to the Lean, Agile and Leagile paradigms that enabled to match the supply chain type according to marketplace necessity. Herer et al. (2002) introduced transshipments, which represented a common practice in multi-location inventory systems involving monitored movement of stock between locations at the same level of the supply chain and established a model, how transshipments could be used to enhance both agility and leanness. Stratton and Warburton (2003) explored the role of inventory and capacity in accommodating the lean as well as agile supply chain variation and identified how *Theory of Inventive Problem Solving* (TRIZ) separation principles and *Theory of Constraints* (TOC) tools might be combined in the integrated development of responsive and efficient supply chains. Prince and Kay (2003) described the circumstances on which manufacturing organizations required an integrated agile and lean characteristic in their supply chain. They also described the development of the virtual group (VG) concept, which was the application of virtual cells to functional layouts. VGs enabled the appropriate application of lean and agile concepts to different stages of production within a factory. The identification of VGs was achieved through enhanced production flow analysis (EPFA). Bruce et al. (2000) discussed the characteristics of the textiles and apparel industry and identified the perspectives of leanness, agility and leagility within existing supply chain fiction which offered as solutions to achieving quick response and reduced lead times.

Narasimhan et al. (2006) attempted an empirical study to determine whether leanness and agility forms occurred with any degree of uniformity in manufacturing plants. The result illustrated the existence of homogeneous groups that resembled lean and agile performing plants. They identified important differences pertaining to their constituent performance and also revealed that while the pursuit of agility might presume leanness, pursuit of leanness might not presume agility. Agarwal et al. (2006) presented a framework which encapsulated the market sensitiveness, process integration, information driver as well as flexibility measures of supply chain performance. They investigated the relationship among lead-time, cost, quality and service level and presented a case study on three types of supply chain viz. lean, agile and leagile in the context of fast moving consumer goods business. Krishnamurthy and Yauch (2007) proposed a theoretical model of leagile manufacturing and analyzed the utility of leagility concept to a single corporate with multiple business units. They explained whether a decoupling point would be necessary to distinguish the lean and agile portions of the enterprise.

Rahimnia and Moghadasian (2010) presented a case study to apply the decoupling point concept in a healthcare delivery system considering the leagile concept. By grouping healthcare services into three pipelines the aforesaid study identified decoupling points for the supply chain. It also argued that while discussing leagility in a professional service organization the important role of human resources should be highlighted. Chan et al. (2009) proposed an integrated process planning and scheduling model inheriting the salient features of outsourcing; and leagile principles to compete in the existing market scenario. The authors also proposed a new hybrid Enhanced Swift Converging Simulated Annealing (ESCSA) algorithm to solve the complex real-time scheduling problems. It had an inherent feature of the Genetic Algorithm (GA), Simulated Annealing (SA) and the Fuzzy Logic Controller (FLC). Rahimnia et al. (2009) highlighted the application of leagility and its characteristics in a mass service organization. Despite the low customization in mass services, fast food restaurants faced changing needs of the customers. To respond to these demands, the case organization could adopt new strategies so that it could be able to serve the customer with short lead times, low costs and high variety. Huang and Li (2010) illustrated how a personal computer original equipment manufacturer (OEM) in Taiwan achieved leagility through re-engineering of its supply chain. The case study showed how the company adjusted its production processes from build-to-order (BTO) to configuration-to order (CTO) so as to achieve leagility.

Konecka (2010) emphasized the importance of the risk management in supply chains strategy such as lean, agile and leagile. These studies facilitated the choice of an appropriate supply chain strategy based on the risk analysis. Moron and Haan (2011) presented a practical case study on polish distributer in Poland. They stated that during the volatile period an agile approach provided the flexibility and competitiveness needed. However, when the market matured; the overly expensive agility caused last minute crisis; then a lean approach enabled the optimization of processes needed to supply customer in a more reliable way.

Azevedo et al. (2012) proposed an index to evaluate the extent of agility and leanness of individual companies and the corresponding supply chain. The index was obtained from a set of agile and lean supply chain practices integrated in an assessment model named Agile and Delphi technique which was used to develop a series of weighted agile and lean supply chain management practices and also the importance of the paradigms through experts in automotive. Soni and Kodali (2012) addressed the issue of lack of standard constructs in frameworks of lean, agile and leagile supply chain by evaluating reliability and validity of lean, agile and leagile supply chain constructs in Indian manufacturing industry. Principle Component Analysis (PCA) was performed on these constructs to find out the pillars of each type of supply chain followed by evaluating reliability and validity of these pillars to establish the underlying constructs.

1.3 Motivation and Objectives

The distribution of the work done so far in various areas of agility has been shown in Fig. 1.2 by means of a pie chart. It has been observed that out of 100% (total number of research articles studied), 19% work has been conducted on development of conceptual framework, modeling of agile manufacturing, understanding of hierarchy of agile providers/capabilities, agile attributes as well as agile criterion. 14% work has been carried out focusing agile supply chain management. 17% work has been documented in literature aiming at agility evaluation. Agility implementation, agile manufacturing system design, information system agility and leagility correspond to 16%, 9%, 7% and 18% of the past studies conducted.

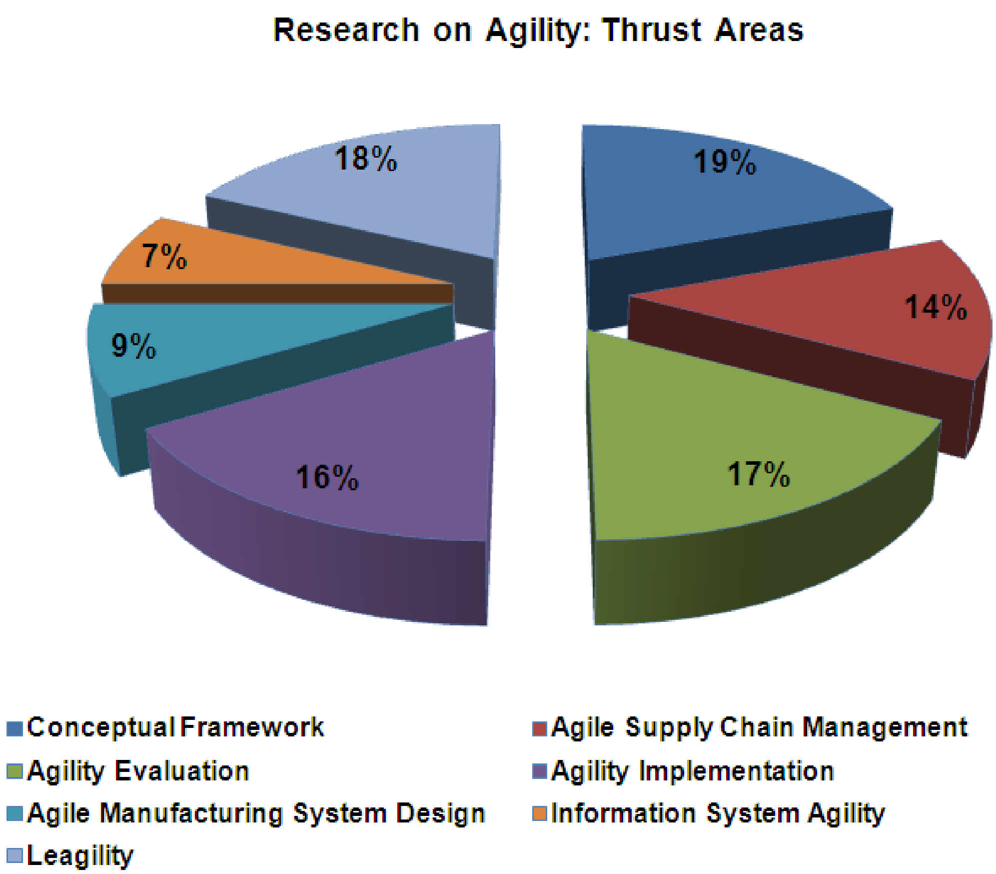

Fig. 1.2: Distribution of the work carried out on various aspects of agility

Agility evaluation and related aspects have always been a major area of concern for the industrialists, management practitioners as well as academicians. Though 17% work has been covered in the area of agility evaluation; the research is still being continued and outcome are being reported which indicates that there is enough scope for further research as well as value addition in this important aspect.

It is definite that, one cannot claim that he/she reviewed all/every academic publication in agile manufacturing, or more specifically, agility evaluation. But the one has to go through the detailed literature review (as more as he/she can collect) and based on this to identify the research gap following with research objectives are articulated. Therefore, based on the volume of literature has been studied, a statistics has been provided showing that out of the total number of research articles studied; it has been found that only 17% of that addressed on agility evaluation. The 17% obviously being a considerable lesser amount; therefore, the work has been motivated to investigate in this particular area.

Rationale for studies has been presented from the perspective that specific gaps in knowledge have been observed from a review of literature. The research gaps have been identified below.

The main problem that arises in course of agility estimation is due to the subjectivity of evaluation indices (drivers/provides-attributes-criterions). In order to tackle this, pioneers put effort to a considerable extent which is evident from the supportive literature. It is felt that the methodologies, tools and techniques available in existing literature, towards agility appraisement, need to be refined. The limitations as well as assumptions of the existing tools need to be overcome. It is indeed necessary to develop an efficient, logical and flexible appraisement module applicable for agility assessment as well as monitoring of existing agility extent. The extent of literature suggests that majority of available literature on agility evaluation, although extensive work has so far not sought to identify and analyze the drivers and obstacles for implementation of agile manufacturing in Indian manufacturing firms so as to enable the managers in decision-making (in relation to agility appraisement, agility benchmarking as well as suppliers selection in agile supply chain).

The prime objectives of this thesis have been highlighted below:

1. To identify and analyze the drivers and obstacles for implementation of agile manufacturing in Indian manufacturing firms so as to enable the managers in decision-making.

   Agility can be explained in terms of agile capabilities (called drivers or enablers), agility attributes as well as agility criterions. It is basically a three-level hierarchy. All the evaluation indices (capabilities/attributes/criterions) are interrelated to one another and their aggregated influence affects overall agility degree. While implementing agility concepts in manufacturing (the supply chain), the key success factors (i.e. evaluation indices) and their relationship need to be properly understood. The factors that boost up agility; and those trying to obstruct agility (barriers) are to be critically analyzed.

2. To develop a methodology for agility appraisement in manufacturing firms.
   For organizations those have already implemented/adapted agility concepts in manufacturing (of organizational supply chain); it is indeed necessary to go for agility appraisement. Such agility assessment may be helpful in monitoring ongoing performance extent of the existing agility inspired practices, in identifying ill-performing areas (agility barriers) and in planning future action plans in order to boost up (enhance) overall agility degree.
3. To propose a methodology for benchmarking of agile enterprises so that best practices can be transferred to non-performing units.
   Benchmarking of agile enterprises may help in identifying best agile practices. The overall performance extent of different agile Industries can be compared. Benchmarking of best agile practices can easily be transmitted to the industries; organizations can follow their peers in order to improve agile performance in future.
4. To propose a methodology for supplier selection in agile supply chain.
   Supplier selection is an important aspect in agile supply chain. Traditional suppliers' selection criterions need to be modified/ restructured to facilitate such decision-making problems in agile supply chain. Most of the selection criterions being subjective in nature; a fuzzy embedded supplier appraisement module is indeed necessary to be developed as fuzzy logic has the capability of dealing with inherent vagueness, inconsistency, imprecision and incompleteness associated with human judgment of qualitative evaluation in information.

The main problem that arises in course of agility estimation is the issue of subjectivity. Agility itself can be described by some capabilities (enablers)-attributes as well as criterions. Most of these evaluation indices are qualitative in nature which cannot be evaluated by exact numeric score. The extent of appropriateness (rating or weight) is generally judged by the Decision-Makers (DMs). Subjectivity of human judgment (based on human perception) brings uncertainty, inconsistency, imprecision as well as vagueness in the decision-making. Therefore, exploration of fuzzy logic, grey numbers theory comes into the picture to facilitate the said decision-making problem solving.

The thesis has been organized in such a manner that the prime objectives (as mentioned earlier) can be addressed in subsequent chapters, thus maintaining an appropriate chronological order. Different chapter deals with different aspects of agility appraisement (agility evaluation in fuzzy/grey context, identification of agile capabilities/drivers/obstacles, agile enterprise benchmarking as well as agile suppliers selection) Therefore, in each chapter, background and relevance of the current sub-theme (problem statement) of the entire work has been provided.

Attempts have been made to robustly root the problems associated agile evaluation within the literature that addresses research priorities and the current research agenda within agility (evaluation). The following references have been cited which explicitly state that the scope of research in agility appraisement appears as an area of interest for scholarship (Richard et al., 1997; Gunasekaran, 1999; Ramesh and Devadasan, 2007).

Motivated the paper by (Stuart et al., 2002) in order to get an idea on framing research questions; the following research questions have been introduced in the thesis which is in appropriate alignment to the prime objectives of the thesis.

1. What is the effective way (tool/technique) in order to align agility capabilities/enablers/derivers in perspective of Indian manufacturing firms?

2. How subjectivity of evaluation indices can be taken care of in decision-making for agility evaluation, benchmarking of agile enterprises as well as suppliers selection. What is the appraisement platform to aid agility related decision-making?

3. Can overall agility index be quantified?

1.4 Research Methodology

The justification for the choice of the overall research methodology has been introduced here. To start with the classification of case research as described by Voss et al. (2002):

A case study is a history of a past or current phenomenon, drawn from multiple sources of evidence. It can include data from direct observation and systematic interviewing as well as from public and private archives. In fact, any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important (Leonard-Barton, 1990).

A case study is a unit of analysis in case research. It is possible to use different cases from the same firm to study different issues, or to research the same issue in a variety of contexts in the same firm. Case research is the method that uses case studies as its basis. Meredith (1998) cites three outstanding strengths of case research put forward by Bebensat et al. (1987):

1. The phenomenon can be studied in its natural setting and meaningful, relevant theory generated from the understanding gained through observing actual practice.

2. The case method allows the questions of why, what and how, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon.
3. The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood.

Case studies can be used for different types of research purposes such as exploration, theory building, theory testing and theory extension/refinement (Voss et al., 2002).

Exploration

In the early stages of many research programs, exploration is needed to develop research ideas and questions. Many doctoral theses begin with one or more case studies in order to generate a list of research questions that are worth pursuing further (e.g. Frohlich, 1998).

Theory building

A particular area where cases are strong is theory building. “Nothing is so practical as a good theory” (Van De Ven, 1989). Theory can be considered as being made up of four components: definitions of terms or variables, a domain-the exact setting in which the theory can be applied, a set of relationships and specific predictions (Wacker, 1998).

A theory may be viewed as a system of constructs and variables in which constructs are related to each other by propositions and the variables are related to each other by hypotheses (Baccarach, 1989). Without theory, it is impossible to make meaningful sense of empirically-generated data, it is not possible to distinguish positive from negative results, and empirical research merely becomes ‘data-dredging” (Handfield and Melnyk, 1998). If we are to ground theory on data, then a large and rich amount of primary data is needed, and case studies are a prime source of this (McCutcheon and Meredith, 1993). Cases are particularly useful when there is uncertainty in the definition of constructs (Mukherjee et al., 2000).

Theory testing

Despite its limited use for theory testing, case study research has been used in the operations management field in order to test complicated issues such as strategy implementation (e.g. Pagell and Krause, 1999; Boyer and McDermott, 1999; McLachlin, 1997). When case study research is used for theory testing, it is typically used in conjunction with survey based research in order to achieve triangulation. This is the use and combination of different methods to study the same phenomenon, so as to avoid sharing the same weakness (Cook and Campbell, 1979; Campbell and Fiske, 1959; Jick, 1979).

Theory extension/refinement

Case studies can also be used as a follow-up to survey based research in an attempt to examine more deeply and validate previous empirical researches (Voss et al., 2002).

Overall, operations management is a very dynamic field in which new practices are continually emerging. Case research provides an excellent means of studying emergent practices. Case research both builds on theory and is an excellent means for development of theory in operations management (McCutcheon and Meredith, 1993).

The category that the present study precisely falls within has been indicated below (against individual objectives/aspects addressed in the thesis).

I. To identify and analyze the drivers and obstacles for implementation of agile manufacturing in Indian manufacturing firms so as to enable the managers in decision-making. (<u>Theory Building</u>)

II. To develop a methodology for agility appraisement in manufacturing firms. (<u>Theory testing and refinement</u>)

III. To propose a methodology for benchmarking of agile enterprises so that best practices can be transferred to non-performing units. (<u>Theory testing and refinement</u>)

IV. To propose a methodology for supplier selection in agile supply chain. (<u>Theory testing and refinement</u>)

1.5 Organization of the Present Dissertation

The major focus areas (coverage) of the present work have been furnished in Fig. 1.3. The thesis has been organized as follows:

Chapter 1 (Research Background) highlights extensive literature review and motivation of the present work. The objectives of the present study have been determined as well. This thesis mainly focuses on understanding and proper alignment of agility drivers (providers/capabilities), agility attributes and agility criterions towards assessing agility. Development of agility appraisement module applicable for supply chain, mass customized system, and organizational level is the prime motivation of the thesis work. Application of a variety of Multi-Criteria Decision Making (MCDM) tools coupled with the concept of fuzzy logic as well as grey relation theory towards agility index assessment and related managerial decision-making has been attempted through empirical research and case study.

Chapter 2 (An Understanding on Interrelationship of Agile Enablers/Drivers in Indian Manufacturing Firms) focuses on application of Interpretive Structural Modeling (ISM) and the concept of Factor Analysis (FA) in order to provide extent body of knowledge on interrelationship of agile drivers towards assessing organizational agility in Indian perspective.

Chapter 3 (Development of Agility Appraisement Modules in Industrial Supply Chain) attempts to develop different appraisement modules (procedural hierarchy) towards agility index estimation. Generalized Fuzzy Numbers (GFNs), Interval-Valued Fuzzy Numbers (IVFNs) adapted from fuzzy set theory along with grey numbers and the concept of grey possibility degree (adapted from grey relation theory) has been tactfully utilized to facilitate agility evaluation and related decision-making. The concepts of fuzzy numbers ranking by (i) rank, mode, divergence, spread (ii) maximizing set and minimizing set theory, (iii) Degree of Similarity (DOS) have been utilized in indentifying various agile barriers (obstacles towards achieving agility). The proposed agility appraisement module has been case studied in two Indian industries (i) automobile as well as (ii) railway construction in order to investigate the existing agile scenarios of the said organizations.

Chapter 4 (Organizational Agility, Benchmarking of Agile Systems and Analysis of Risk in Decision-Making) provides important insights towards appraising organizational agility, benchmarking of agile systems and analysis of risks in agile assessment decision-making. A comparative study has been made on application of grey theory as well as Fuzzy-TOPSIS towards benchmarking (ranking) of candidate MC systems. In later part of this chapter, the influence of decision-makers' risk bearing attitude on overall organizational agility assessment has been critically studied.

The aspects of supplier selection in agile supply chain (agile supplier selection or suppliers possessing agile attributes) have been covered in **Chapter 5 (Supplier Evaluation and Selection in Agile Supply Chain)**. Firstly, a supplier selection cum evaluation (appraisement) platform has been developed in fuzzy environment. The concept of ranking fuzzy numbers by (i) 'maximizing set and minimizing set' and (ii) Degree of Similarity have been efficiently explored to identify ill-performing areas corresponding to a particular candidate supplier.

This study has been extended with an application of a recently developed MCDM tool i.e. MOORA (Multi-Objective Optimization by Ratio Analysis) in combination with fuzzy logic (Fuzzy-MULTIMOORA) to facilitate supplier selection decision-making in agile supply chain.

Finally, **Chapter 6 (Executive Summary and Conclusions)** complies and summarizes outcome of the present research; based on which conclusions have been drawn and future research directions have been clearly identified as well.

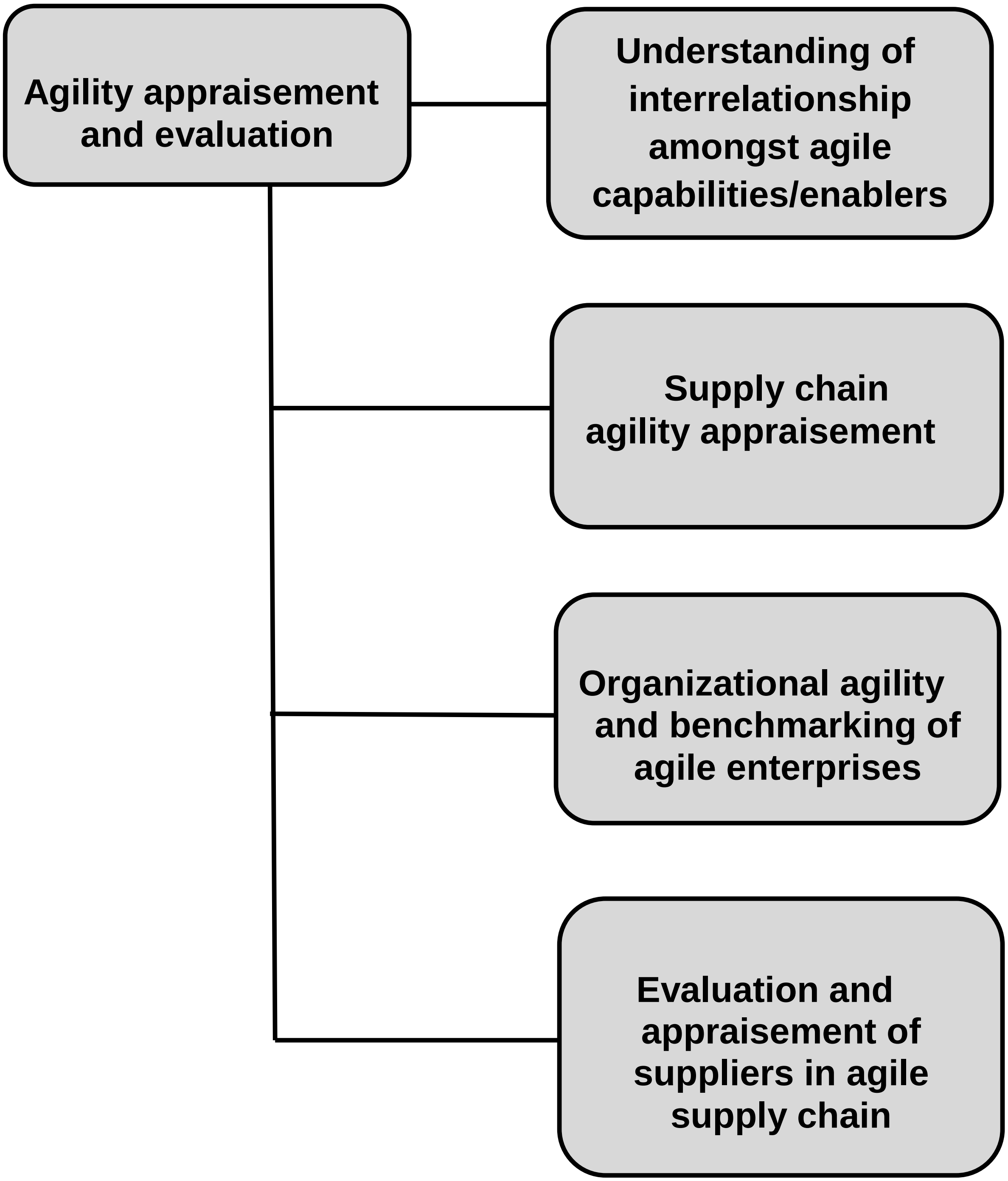

Fig. 1.3: Focus areas (coverage) of the present work

CHAPTER 2

AN UNDERSTANDING ON INTERRELATIONSHIP OF AGILE ENABLERS/DRIVERS IN INDIAN MANUFACTURING FIRMS

2.1 Interrelationship of Drivers for Agile Manufacturing: An Indian Experience

2.1.1 Overview

Change seems to be one of the enterprise's important characteristics to gain competitive advantage in ever-increasing business environment. Agile Manufacturing (AM) is viewed as a winning strategy by the organizations to quickly adapt and orient themselves in changing environments. It is important to identify various agile drivers which can be deployed collectively to make the organization profit making one in the market place. All the agility drivers (or characteristics) do not require the same focus and attention on the part of decision-makers. To this end, Interpretive Structural Modeling (ISM) has been adopted to study drivers of agile concept systematically. ISM is capable of addressing the complexities and dynamics of an issue to ease the decision making process. The technique presents a hierarchical structure that depicts the direct and indirect linkages amongst various components in a system based on primacy, precedence, and causality over and among each other. The key drivers for implementation of agile concept in manufacturing context have been identified in an Indian environment.

2.1.2 Introduction

Today, the business enterprises must restructure and reengineer themselves to overcome the challenges of demanding customers who rapidly change their needs (Bunce and Gould, 1996). The changing customer and technological requirements compel manufacturers to develop new business strategies in order to become competitive in the marketplace. As ''Change'' seems to be one of the important characteristics, the enterprises are contemplating to adopt agile manufacturing, because, it quickly adopts changing environments. Agility enables enterprises to thrive in face of competitive environment of unpredictable and continuous change (Richards, 1996). As economy of scale and mass production results in inflexible plants which cannot be easily reconfigured, it is essential to develop more flexible and responsive organizations (Gould 1997; Moore, 1995). To cope up with market instability, enterprises now look upon to speed, quality and flexibility rather than cost which are being emphasized as responsive to the unique needs of customers and markets (Gunasekaran et al., 2008). The agility framework provides a platform for industries so that they can better placed themselves to exploit new and emerging opportunities in the marketplace (Poolton et al., 2008; Browne et al., 1995). Four main aspects of agile manufacturing such as agility drivers, strategic abilities, agility provider and agility capabilities must be understood thoroughly before its implementation (Sharifi et al., 2001). To respond the changes, some drivers are required which force a company to revise its existing strategy, adopt an agility strategy and admit the need to become agile. Therefore, agility drivers take the company to a new position in response to the competitive advantage. This enhances to revisit the company's strategy structure and reconstruct it according to agile concept (Kidd, 1994; Goldman et al., 1995). Strategic abilities allow to successfully dealing with the changes and they include attributes like as responsiveness, competency, quickness, flexibility, and collaboration. Agility capabilities can be achieved by agility providers from four predominant areas such as organization, technology, people and innovation. The integration of these four areas is required to provide agility capabilities (Kidd, 1994). All the agility providers do not warrant the same focus and need the attention of the decision makers to segregate them into different classifications.

The automobile industries are a high capital investment, high technology and high product integrated industry. Agile Manufacturing system acts as a strategic initiative which helps to survive in the unpredictable and ever-changing market with effective cost to respond dynamic customers' demand in the automobile industries. Elkins et al. (2004) used descriptive influence diagram, spreadsheet model as well as a decision tree model for gain insight into the value of system agility. However, the study did not lead to explore interaction among various agile enablers. Garbie et al. (2008) pointed out few components that assisted in enhancing agility effectively from a gamut of enablers. Therefore, a set of enablers needs to be explored and their interaction must be studied. In addition, drivers and dependents which are reliant on the drivers and facilitators/enablers should be prioritized. As the success of automobile companies depend mainly upon automobile manufacturer and distributor partnership, complexity of partnership was studied using a systematic procedure involving a large number of system variables which acted as driving forces (Chen and Wu, 2010).

It is generally felt that individuals or group of decision makers encounter difficulties in dealing with complex issues or systems. The complexity of the issues or systems is due to the presence of a large number of elements and interactions among these elements. The presence of directly or indirectly related elements complicates the structure of the system which may or may not be articulated in a clear fashion. It becomes difficult to deal with such a system in which structure is not clearly defined. Hence, it necessitates the development of a methodology which aids in identifying a structure within a system. Interpretive structural modeling (ISM) is such a methodology. ISM approach gives a better understanding of a system structure and draws up useful guideline in generating a graphical representation of the structure (Vivek et al., 2008). Hasan et al. (2007) used ISM approach to identify barriers in agile manufacturing context, but literature is seemed almost silent to explore enablers and their interrelationship of enablers in Indian manufacturing environment.

In this work, drivers for implementing agile manufacturing in Indian context have been identified. The interrelationship among the drivers has been developed using ISM. The study will help the managers to formulate policies keeping in view of complex interdependence of the drivers for the successful implementation of agile manufacturing. The hierarchy developed in this study is quite generic and can be adopted in any manufacturing condition once the drivers have been identified clearly to address the issues of a complex system.

Thus, the ISM based model proposed here for identification of drivers of AM can provide the decision-makers to extract realistic representation of the overall structure in course of implementing AM system. This can help in deciding the priority to proactively take steps in combating these drivers.

2.1.3 Understanding of State of Art

The term "agile manufacturing" was coined by a US Government sponsored research program at Lehigh University and latter at MIT (Nagel et al., 1991) realizing the fact that competitive advantage comes from time rather than cost today. Agile manufacturing focuses on speed and flexibility not cost (Gunasekaran et al., 2008). Hence, manufacturers are now striving to become agile (Booth, 1996; Ward, 1994). However, agility, adaptability and leanness are three pillars of mutually supporting concepts to improve competitiveness and prospects of survival in an increasingly global and volatile business environment (Goldman et al., 1995). To provide customer driven products and services in a continuous changing environment, agility paradigm is a successful application of competitive bases responding to speed, flexibility, innovation, and quality by the means of the integration of reconfigurable resources (Yusuf et al., 1999).

In response to changes in the environment, organizational flexibility is considered as the organization's major ability to adjust its internal structures and processes (Reed and Blunsdon, 1998). Each company can achieve agility based on the audit that relates the agility dimensions with current and future company operations, cooperation to enhance competitiveness, organizing to master changes and leveraging the impact of people and information (Goldman et al., 1995). Jackson and Johansson (2003) proposed agility capabilities in slightly different four dimensions such as product-related change capabilities, change competency within operations, internal and external co-operation, and people, knowledge, and creativity. Yusuf et al. (1999) distinguished three aspects of agility related to different level of enterprise like elemental agility, micro-agility, and macro-agility. Sharifi et al. (2001) classified the attributes of an enterprise related to agile manufacturing into agility drivers, strategic abilities, agility providers and agility capability. The agility index used for agile measurement is the combination of agility capabilities intensity levels in various dimensions of agile manufacturing. Zhang (2007) developed a taxonomy in which agility drivers, capabilities, and providers were used as constructs and shown how agility drivers acts as driving forces to obtain agility capabilities to perform various tasks fulfilling strategic requirements. Ren et al. (2000) proposed an Analytical Hierarchical Process (AHP) approach for measuring agility of the enterprise. Many researchers proposed fuzzy logic knowledge-based framework for measuring agility in imprecise and uncertain environment (Lin et al., 2006a, b; Tsourveloudis and Valavanis, 2002). This framework considers four infrastructure of agile manufacturing such as production, market, people and information. Plant, processes, equipment, layout, and material handling can be measured in terms of time and cost and included in production infrastructure. Market infrastructure is focused on the external environment of the enterprise which depends upon customer service and market feedback.

Agile enterprise networks must be collaborative networks that aim to move forward in a decentralized and dynamical way instead of static hierarchical cooperation and value chains (Ivanov et al., 2007). Training and motivation of the personnel are important aspects to improve people infrastructure. Information infrastructure refers to information flow within and outside of organization measured by the ability to capture, managing and sharing information. Every successful organization must work towards incorporating agile entities into their supply chains. The change phenomenon needs a thorough understanding of variables that impact the agility of supply chains. All the variables do not require the same focus; rather, a set of variables (driver variables) which needs maximum attention must be identified. An agility improvement index was proposed based on these driver variables to compare various supply chains on agility improvement efforts through an integrated approach of interpretive structural modeling (ISM) and graph theory (Faisal et al., 2007). In a complex system, structuring of the variables and obtaining interrelation among them is always a matter of concern. Warfield (1973) proposed ISM methodology which is a computer assisted learning process that enables individuals or groups to develop a map of the complex relationships among many elements involved in a complex situation. Wang et al. (2008) used ISM to summarize the critical barriers hindering the project of energy saving in China and explained the interrelationships among them. Vivek et al. (2008)

resorted to ISM to establish changing emphases of the specific elements in offshore alliances because ISM approach gives a better understanding of a system structure and draws up a useful guideline in generating a graphical representation of the structure. The process transforms complex systems through sorting the system variables into groups of various characteristics and prioritization of group of variables can be made using Multi-Attribute Decision Making (MADM) approach (Chen and Wu, 2010).

ISM is often used to provide fundamental understanding of complex situations as well as to put together a course of action for solving a problem (Anantatmula et al., 2005; Warfield, 1976). It drives individuals or groups to develop a map of the complex relationships between many elements involved in a complex decision situation (Charan et al, 2008). Saxena et al. (1992) applied the ISM for the modeling of variables of energy conservation in an Indian cement factory to identify key variables using direct as well as indirect interrelationships among the variables. Mandal and Deshmukh (1994) used ISM to analyze some of the important criteria on vendor selection and showed the inter-relationships among criteria. Sharma et al. (1995) used the ISM methodology to develop hierarchy of action required to achieve the future objective of waste management in India. Successful adoption and implementation of agile manufacturing requires a systematic study of its enablers. In this direction, Ramesh et al. (1998) used ISM to derive interrelationships of the variables influencing supply chain collaboration. The interrelationship among barriers for implementing agile manufacturing was studied by Hasan et al. (2007). The relationship among agile enablers is systematically studied using ISM (Hasan et al., 2009). To add value to the previous research, this study aims to identify and determine the relationship among various drivers for implementation of agile manufacturing in an effective and appropriate manner.

2.1.4 An Overview of the ISM Approach

Interpretive Structural Modeling was first proposed by J. Warfield in 1973 to analyze the complex socioeconomic systems. The ISM process transforms unclear, poorly articulated mental models of systems into visible, well-defined models useful for many purposes (Ahuja et al, 2009). It is a method for developing hierarchy of system enablers to represent the system structure (Bottani, 2009). ISM is an interactive learning process in which a set of different and directly related elements are structured into a comprehensive systematic model. A systemic way of identification of relationship among various enablers helps to evaluate the complexities and dynamics involved in the implementation of agile manufacturing (Hasan et al., 2009). The basic idea of ISM is to decompose a complicated system into several subsystems (elements) by using practical experience of experts and their knowledge. ISM is a computer-assisted learning process that enables individuals or groups to develop a map of the complex relationships between many elements involved in a complex situation. The complexity of the issues or systems is due to the presence of a large number of elements and interactions among these elements as the drivers for execution of agile manufacturing. The presence of directly or indirectly related elements complicates the structure of a system which may or may not be articulated in a clear fashion. The ISM is capable of identifying a sophisticated system hierarchy through a series of matrix manipulation, which otherwise, would be rather difficult in a system with a wide variety of system variables (Gorvett and Liu, 2007).

The important characteristics of ISM are given as follows.

(a) This methodology is interpretive as the judgment of the group decides whether and how the different elements are related.

(b) It is structural on the basis of mutual relationship. An overall structure is extracted from the complex set of elements.

(c) It is a modeling technique as the specific relationships and overall structure are portrayed in a digraph model.

(d) It helps to impose order and direction on the complexity of relationships among various elements of a system.

(e) It is primarily intended as a group learning process but individuals can also use it.

The various steps involved in the ISM methodology are discussed as follows.

Step 1: Identification of drivers: The elements of the system are identified which are relevant to the problem or issue and then achieved with a group problem-solving technique like brain storming sessions.

Step 2: Contextual Relationship: From the enablers identified in step 1, a contextual relationship is identified among drivers with respect to whom pairs of variables would be examined. After resolving the driver set and the contextual relation, a structural self-interaction matrix (SSIM) is prepared based on pair-wise comparison of drivers of the system under consideration. Four symbols are used to denote the direction of relationship between the criterion (i and j).

V - for the relation from element i to element j and not in both directions;

A - for the relation from element j to element i and not in both directions;

X - for both the directional relations from element i to element j and j to i;

O - if the relation between the elements did not appear valid.

Step 3: The SSIM is transformed into a binary matrix called the initial reachability matrix by substituting V, A, X, O by 1 and 0 as per the following case. The rules for the substitution of 1's and 0's are listed below.

I. If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.

II. If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.

III. If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.

IV. If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0

Step 4: The reachability matrix obtained in step 3 is converted into the final reachability matrix by checking it for transitivity. The transitivity of the contextual relation is a basic assumption in ISM which states that if element A is related to B and B is related to C, then A is related to C.

Step 5: The final reachability matrix thus obtained is converted into the canonical matrix format by arranging the elements according to their levels.

Step 6: From the canonical matrix form of the reachability matrix, a directed graph is drawn by means of vertices or nodes and lines of edges and the transitive links are removed based on the relationships given above in the reachability matrix. The resultant digraph is converted into an ISM by replacing enabler nodes with statements.

2.1.5 Results and Discussions

It is vital to identify the critical drivers which are mainly responsible to move the industry towards success. If the driving forces and their interrelationship are understood properly, their prioritization and categorization becomes easy. A decision-making method is adopted in which sixteen experts from the industrial sectors and academia is consulted in identifying the driving forces and the nature of contextual relationship between various factors. As one success factor leads to another based on this contextual relationship, a structural self-interaction matrix (SSIM) is developed showing the relations. After a thorough discussion with focus groups from Indian manufacturing companies, the following drivers have been arrived through consensus.

Drivers for Agile Manufacturing

1. **Widening customer requirements**: The changing market scenario, demand for individualized products and services, increase in quality expectations, and need to quicker delivery of products are some of the factors that customers are very much concerned now-a-days.
2. **Competition criteria**: Always these exists intense pressure on manufacturing companies on cost of products and demand of some innovations which leads to huge competition in the market. Some other criteria include increasing pressure of global markets, flexibility to changes in market requirement and responsiveness.
3. **Culture of rapid change**: Because of increasing rate of change in product models and product life time shrinkages, a culture of rapid adaptation should be incorporated as corporate culture.
4. **Technological advancements**: To cope up with the today's customers/market need, companies are focused to introduce more efficient and faster and economic production facilities, new soft technologies and inclusion of information technology in new hard technologies.
5. **Social factors**: This factor includes environmental pressures, workforce/workplace expectations, and legal pressures.
6. **Integration and proactivity**: To fulfill the customers' expectations manufacturers have to integrate themselves with them to identify their problems and requirements. Apart from this, they must acquire capabilities just ahead of what may be the need of today. In this way, proactivity may lead to strategic advances for competing in the turbulence of the global market.
7. **Reduced lead time**: To remain competitive, manufacturers are required to produce products in sufficient quantity at lower cost, with high quality and decreasing lead time.

Based on experts' opinion, the next step is to establish contextual relationship through brainstorming process. The ISM methodology explores expert's opinion using brainstorming session for the development of contextual relationships of different driving forces. Here contextual relationship of type "helps to achieve" has been used to formulate the SSIM as shown in Table 2.1. The symbols V, A, X and O used SSIM are explained as follows:

1) Driver 1 helps to achieve driver 2, thus the relationship between them is denoted by V.
2) Driver 2 can be archived through driver 3, thus the relationship between them is denoted by A.
3) Driver 1 and 4 helps to achieve each other .Therefore, the relationship between them is X.
4) No relationship exists between driver 1 and 5, therefore the relationship is denoted by O.

Table 2.1: Structural Self-Interaction Matrix (SSIM)

Agile Drivers		7	6	5	4	3	2
1	Widening Customer Requirements	V	V	O	X	X	V
2	Competition Criteria	V	V	V	V	A	
3	Culture of Rapid Change	O	V	V	V		
4	Technological Advancements	V	V	O			
5	Social Factors	O	V				
6	Integration and Proactivity	O					
7	Reduced Lead Time						

The SSIM format has been transformed into initial reachability matrix format by transforming the information in each entry as explained in Step 3 of Section 2.1.4 as shown in Table 2.1.

Table 2.2: Initial Reachability matrix

Drivers	1	2	3	4	5	6	7
1	1	1	1	1	0	1	1
2	0	1	0	1	1	1	1
3	1	1	1	1	1	1	0
4	1	0	0	1	0	1	1
5	0	0	0	0	1	1	0
6	0	0	0	0	0	1	0
7	0	0	0	0	1	0	1

The reachability matrix has been checked for transitivity rule as described in Step 4 in Section 2.1.4. If the transitivity rule is not found to be satisfied, the SSIM is reviewed again and modified by specific feedback about transitivity relation from the experts. The driving power of a particular element is the total number of elements including itself, which may help to achieve. The dependence is the total number of elements which may help achieving it. The final reachability matrix has been shown in Table 2.3 along with the driving power and dependence of each element.

Table 2.3: Final Reachability matrix

Drivers	1	2	3	4	5	6	7	Driving Power
1	1	1	1	1	1*	1	1	7
2	1*	1	0	1	1	1	1	6
3	1	1	1	1	1	1	1*	7
4	1	1*	1*	1	0	1	1	6
5	0	0	0	0	1	1	0	2
6	0	0	0	0	0	1	0	1
7	0	0	0	0	1	1*	1	3
Dependence	4	4	3	4	5	7	5	

Table 2.4: Partition of Reachability Matrix: 1st iteration

Drivers	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7	1,2,3,4	1,2,3,4	
2	1,2,4,5,6,7	1,2,3,4	1,2,4	
3	1,2,3,4,5,6,7	1,3,4	1,3,4	
4	1,2,3,4,6,7	1,2,3,4	1,2,3,4	
5	5,6	1,2,3,5,7	5	
6	6	1,2,3,4,5,6,7	6	I
7	5,5,7	1,2,3,4,7	7	

From the final reachability matrix, the reachability and antecedent set for each driver has been found. The reachability set consists of the element itself and the other elements which it may help to achieve whereas the antecedent set consists of the element itself and the other elements which may help in achieving it. Subsequently, the intersection of these sets is derived for each driver. The drivers for which the reachability and the intersection sets are the same, they occupy the top level in the ISM hierarchy. The top level elements in the hierarchy would not help achieve any other element above its own level. Once the top level element is identified, it is separated out from the other elements. Then, the same process is repeated to find out the elements in the next level. This process is to be continued until the level of each element is found. These levels help in building the diagraph and the final model. The level partitions in all iterations have been shown in Tables 2.4- 2.7.

Table 2.5: Partition of Reachability Matrix: 2nd iteration

Drivers	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,7	1,2,3,4	1,2,3,4	
2	1,2,4,5,7	1,2,3,4	1,2,4	
3	1,2,3,4,5,7	1,3,4	1,3,4	
4	1,2,3,4,7	1,2,3,4	1,2,3,4	
5	5	1,2,3,5,7	5	II
7	5,7	1,2,3,4,7	7	

Table 2.6: Partition of Reachability Matrix: 3rd iteration

Drivers	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,7	1,2,3,4	1,2,3,4	
2	1,2,4,7	1,2,3,4	1,2,4	
3	1,2,3,4,7	1,3,4	1,3,4	
4	1,2,3,4,7	1,2,3,4	1,2,3,4	
7	7	1,2,3,4,7	7	III

Table 2.7: Partition of Reachability Matrix: 4th iteration

Drivers	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4	1,2,3,4	1,2,3,4	IV
2	1,2,4	1,2,3,4	1,2,4	IV
3	1,2,3,4	1,3,4	1,3,4	V
4	1,2,3,4	1,2,3,4	1,2,3,4	IV

Having identified the levels of elements, the relationship amongst elements has been drawn with the help of an arrow. The diagraph shown in Fig. 2.1 provides information about hierarchy between the elements of drivers.

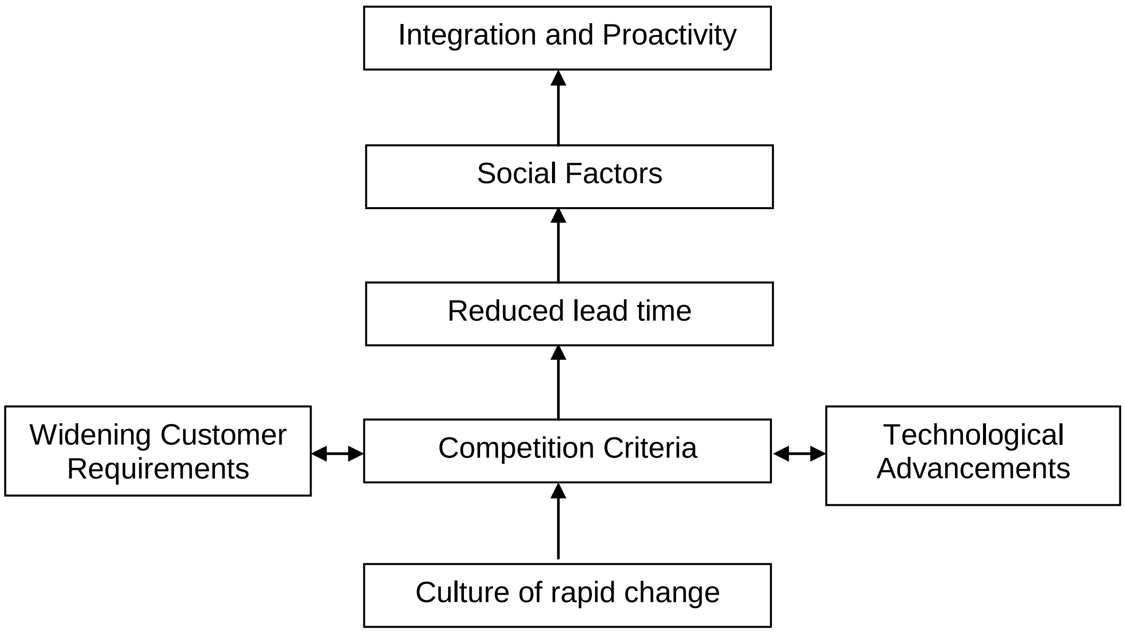

Fig. 2.1: ISM based model for understanding of drivers in agile manufacturing

A MICMAC analysis is carried out to classify the drivers into various clusters based on the driving power and dependence of each driver that influence the implementation of agile manufacturing. The classification is shown in Fig. 2. The drivers in first cluster have weak driving power and weak dependence and are known as Autonomous or Excluded drivers. These drivers have only a few links with the system. In the present study none of the drivers is classified into this category. Another cluster of drivers have weak driving power but strong dependence. These drivers are called depending drivers or result enablers. Driver 7 has a weak driving power but strong dependence on other drivers. This indicates that it requires all other drivers to come together for overcoming difficulties in successful implementation of agile manufacturing. Driver 5 and 6 are also clustered in this category. In the third cluster, drivers having strong driving power and strong dependence are categorized. These drivers are very influent and very dependent at the same time. They are otherwise known as relay drivers. These drivers are very sensitive in the sense that any action on these indicators will have impact on other drivers and amplify pulse on agile implementation. In present case, three drivers such as “Widening Customer Requirements” (Driver 1), “Competition Criteria” (Driver 2) and “Technological Advancements” (Driver 4) are the drivers in this category. The fourth category of drivers is characterized by strong driving power and weak dependence. These drivers are altogether very influent and little dependent. Most of the drivers causing smooth implementation of agile manufacturing thus depend on these drivers. These drivers condition the rest of the system and are also called independent or determinant drivers. These influent drivers are most crucial elements since they can act on the system depending on how much we can control them as a key factor. The analysis reveals that the only driver “Culture of rapid change” (Driver 3) is ranked as independent drivers as this has maximum driver power. This implies that this variable is key driver for successful implementation of agile manufacturing.

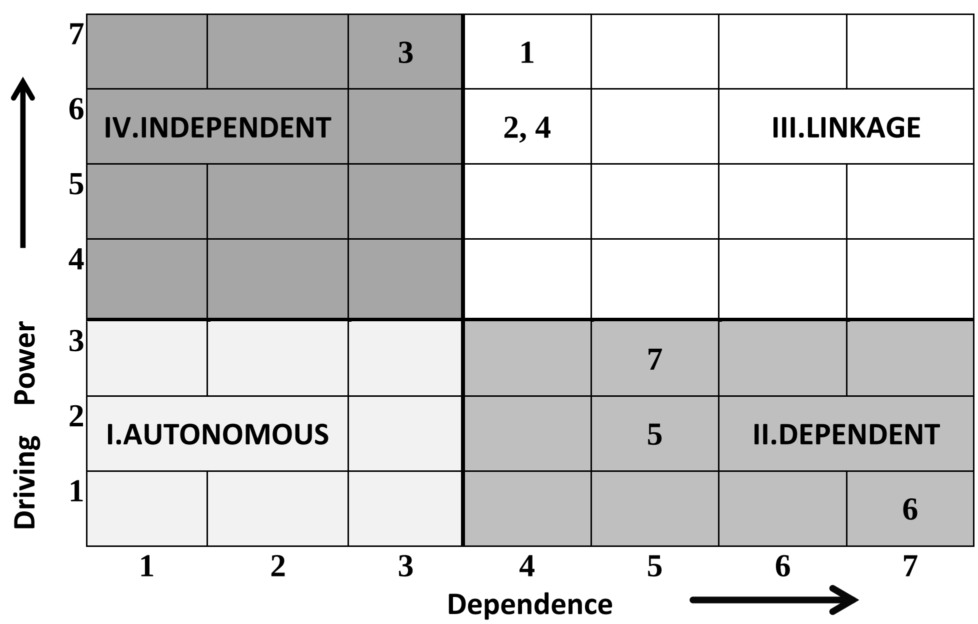

Fig. 2.2: Driving Power-Dependence diagram

2.1.6 Concluding Remarks

Manufacturing firms can improve agility capabilities if agility providers are identified and implemented in various areas of manufacturing such as organization, technology, people and innovation (Danuta and Swierczek, 2009). The integration of these four areas is required to provide agility capabilities in order to effective address various issues related to competition arising from market place. All the agility providers do not warrant the same focus and need the attention of the decision makers to segregate them into different classifications. ISM is a useful tool for exercising a logical thinking in approaching complex issues. Some of the major drivers highlighted for enabling agile manufacturing are tested using ISM model to analyze the interaction between the drivers. The driving power-dependence diagram gives some valuable insights about the relative importance and the interdependencies among the drivers. The insights gained are useful for the managers so that they can proactively deal with these drivers. The methodology proposed here structures the drivers in a hierarchical form for ease of managing them. Thus the ISM based model proposed for identification of drivers of agile manufacturing can provide the decision makers a realistic representation of the problem in the course of implementing agile manufacturing. Driver 5 (Social Factors), 6 (integration and proactively) and 7 (reduced lead time) have weak driving power but strong dependence on other drivers. This indicates that it requires all other drivers to come together for overcoming difficulties in successful implementation of agile manufacturing. Driver 1(Widening Customer Requirements), driver 2 (competition criteria) and driver 4 (technological advancements) have strong driving power and strong dependence. These drivers are highly influent and dependent at the same time and known as relay driver. These drivers should be studied carefully than the others because they are very sensitive in the sense that any action on these indicators will have impact on other drivers. Driver 3 (culture of rapid change) is known as independent driver as it has maximum driver power. This driver is characterized by high driving power and weak dependency. This variable, in fact, is key driver for successful implementation of agile manufacturing. The study can be further extended using structural equation modeling approach to find out the degree of dependence. Also quality function deployment can be applied to further break down the enablers into specific tools.

2.2 Alignment of Dimensions towards Modeling Organizational Supply Chain Agility

2.2.1 Overview

In the present study, the concept and the application of Factor Analysis (FA) to achieve effective dimensions on organizational supply chain agility has been explained. Factor analysis is a statistical approach through which the number and nature of variables, which measure the test, are clarified. Factor analysis is generally performed by combining different variables together, thereby, obtaining a few variables called as an individual factor/dimension. This method determines interrelationship among analysis data and reduces total number variables into less number of factors/dimensions for simplicity in analysis. In the case study of an Indian automobile sector in order to define effective factors describing organizational supply chain agility, on the basis of conceptual model, a questionnaire has been compiled. The survey data obtained thereof, has been analyzed by descriptive statistics and all variables have been categorized finally into thirteen factors (dimensions) through exploratory factor analysis. This would facilitate in estimating organizational overall agility extent and various managerial decision-making.

2.2.2 Research Background

In today's competitive global business scenario, successful survival by facing '*ever-changing environment*' has become one of the major thrust areas for every manufacturing cum production units/industrial sectors, their supply chain. There exist intense competitive pressures on companies due to the pervasive influence of globalization towards improving operational flexibility in an efficient manner for enhanced competitiveness and overall business performance (Ebiringa, 2011). Such pressures include competition from foreign products, new product introduction by competitors, falling product life cycles, unanticipated customer shifts, and advances in manufacturing and Information Technology (Browne et al., 1995). It is also due to the entry of numerous competitors in the world market (Gunasekaran et al., 2008; Saisse and Wilding, 1997). The agility concept highlights the industrial enterprises' attempts to implement and improve their competitive advantage (Kisperska-moron and Swierczek 2009; Rahiminia, et al., 2009).

In the contemporary market scenario, customers demand frequently change in a very unpredictable way. This situation indicates the dynamic nature of customers' demands. Hence, modern manufacturing organizations should be capable of reconfiguring their existing manufacturing system to suit the dynamic customers' demands (Brown and Bessant, 2003). This condition forces for acquiring the new concept of 'agility' and to sift toward agile manufacturing (AM) paradigm. It is the reconfiguration of business relationships, products and processes for being successful in the hyperactive competitive marketplace (Iskanius and Helaakoski, 2009). Agile manufacturing is a new and revolutionary concept of manufacturing as well as assembling of products. It is the next logical step in the evolutionary chain of manufacturing technologies; following on the heels of its predecessors, craft production, mass production, and lean production (Rad et al., 2011). Agile organizations provide flexibility, speed, quality, service, efficiency and enable firms to react deliberately, effectively in a coordinated manner to change in the environment. It increases organizational capability as it provides high quality products with shorter product life cycle, in less delivery time; therefore, it is vital for organizational competitiveness.

Agility is the capability to survive and prosper in a competitive environment of continuous and unexpected change by reacting quickly and effectively to changing markets, driven by customer-designed products and services (Gunasekaran1998, 1999). Agility refers to the strategic ability of an enterprise to adapt and accommodate quickly unplanned and sudden changes in market opportunities and pressures. Measurement of agility index is of prime importance to assess existing agility level, to change/modify strategic concepts in order to improve agility extent. It is a scale the management uses to identify the agile potential of a project or organization/ supply chain. Therefore, it is essential to achieve effective entities on organizational agility.

The agile practices are basic building of agility measurement index. The AM practices aim towards manufacturing capabilities to responsively introduce new products ahead of competitors in order to remain competitive (Dimitropoulos, 2009). So, agility assessment is a method that aims to find out how well agile practices fit into the organization; what are the changing requirement in order to adopt a certain agile practices, and what agile practices would be useful for the company. It analyzes both, the agile and plan-driven practices, tools and methods those are currently used in an organization.

In this research, understanding of measures and metrics for agility evaluation starts with FA technique. The context factor analysis gives a starting point for realizing important agile dimensions which in turn facilitates in-depth motivation for agility assessment. The required practices for agility measurement tool design have been identified through brief literature review.

A conceptual model has been proposed in a hierarchical structure with respect to related agile practices. The said practices in the proposed model have been examined based on a questionnaire; followed by statistical analysis conducted in the later stage. These practices have been prioritized and agility assessment has been carried out on the base of selected agile practices. This study develops a construct for agility evaluation in a particular Indian automobile part manufacturing firm located at eastern part of India. Now-a-days, automotive manufacturing industry is characterized by excessive capacity, low profitability, rigid production structures and overextends product ranges (Wad, 2009). They must implement and maintain a high degree of agile practices due to competitive market and customer pressure.

The approach reveals the practices which needs urgent improvement as these are important towards agility measurement in order to achieve edge over competitors. Such a tool would help the decision-makers (DMs) and company managers to assist them achieving their enhanced agility level.

2.2.3 Understanding of State of Art

Agile manufacturing (AM) is described as new tactics of manufacturing. It emerged after Lean Production (LP). It represents pattern shifts from mass production (MP). It originated from the 21stcentury manufacturing enterprise study that was conducted at *Lehigh University* in the early 1990s (Groover, 2001). Following that, a book entitled “*Agile Companies and Virtual Enterprise*” recognized as the state-of-the-art work on AM was published in 1995. According to Groover (2001),“agile manufacturing can be defined as: (1) an enterprise level manufacturing strategy of introducing new products into rapidly changing markets, (2) an organizational ability to thrive in a competitive environment characterized by continuous and sometimes unforeseen change”. Pham et al. (2008) defined agile manufacturing as the ability to thrive in a competitive environment of continuous unpredictable change and respond quickly to rapidly changing market driven by customer-based value of products and services. The international Cam-I (1998) addressed the capabilities of an enterprise to reconfigure itself quickly in response to sudden changes, but in ways that are cost effective, timely, robust, and of a broad scope. Agility theory seeks to provide matrices for business processes, physical operations, and human resources to respond to rapid and unpredictable changes.

Agile companies tend to reveal the following agile principles: (1) rapid configuration of resources to meet dynamic change of market opportunities; (2) managerial personnel needs and knowledge should be distributed to all level of enterprise on trust base; (3) building business relationships to effectively enhance competitiveness; (4) considerable attention on innovation and entrepreneurship should be highly considered; (5) considerable attention on the value of solutions to customers' problems rather than on the product cost and price.

The Agile Supply Chain (ASC) is an operational strategy, which aims on inducing speed and flexibility in a supply chain (Song et al., 2007). Gunasekaran (1998, 1999) described agile manufacturing as ''the capability to survive and prosper in a competitive environment of continuous and unexpected change by reacting quickly and effectively to changing markets, driven by customer-designed products and services''. Goldman et al. (1995) presented a slightly different definition, with agile manufacturing. In fact, it allows companies to operate profitably in a competitive environment of continually and unpredictably changing customer opportunities.

Some of the conditions in which an agile approach is best suited can be described by the following characteristics: (i) short life cycle products; (ii) high product variety in the face of unpredictable demand; (iii) small volumes and higher profit margins; (iv) competition based on product specification. With this agility, the supply chain more frequently operates in a global context and there is an increasing trend to outsource the supply and manufacturing overseas through a complex supply network (Prater et al., 2001; Masson et al., 2007; Storey et al., 2005) to reduce costs.

In the rapidly changing and continuously fragmenting global market environment, agile potential of organizations is influenced by the surrounding circumstances causing agility drivers vary from one company to another. Consequently, the concept of change is different in different business environments (Shahraki et al., 2011). The objectives also differ from organization to organization as it affects business including different ways and rules to compete in the market, new methods of market penetration. The operation styles of industries also vary. Therefore, strategic plan of the industries becomes highly diversified.

To demonstrate the variety that exist and summarizing key agile characteristics, a valid suitable candidate solution is indeed required for measuring organizational agility. It is postulated that any practical agility metric should provide a situation-oriented specific measurement by taking into account the particular characteristics of the system/enterprise under study; and allow for comparisons among different installations (Tsourveloudis and Valavanis, 2002).

The primary contribution of this paper is to develop successfully a hypothetical structural agility model by understanding and proper alignment of various agile dimensions. The hypothetical structured model has been analyzed quantitatively to generate a best-fit model. There is predominant need for developing a model validated by experimental basis, to know either it is to be fitted suitably to the particular organization and can measure agility extent through this model.

The present work attempts to develop a realistic tool/model to provide industrial sectors for better understanding of the total concept of agility, determining agility needs, assessing current agile practices, determining the capabilities required to become agile. In order to define effective variables (dimensions) on organizational supply chain agility, on the basis of a conceptual model, a questionnaire has been compiled and the data obtained thereof, has been analyzed as a case study in a famous automobile sector located at eastern part of India.

2.2.4 Factor Analysis

Exploratory Factor Analysis (EFA) is a data/ variable reduction technique, which attempts to partition a given set of variables into groups of maximally correlated variables. Jupp (2006) defined it as a set of procedures used to simplify complex sets of quantitative data by analyzing the correlations between variables to reveal the small number of factors which can explain the correlations. Factor analysis (FA) helps convert a large number of variables into a smaller number of variables, called factors, which capture as much information as possible from the original data set (Parasuraman et al., 2004). It is one of the multi-variable methods in which all depended variables is considered and it tried to categorize a lot of variables in several factors (Mashayekhi et al., 2011). As an interdependence statistic tool, FA is based on three main assumptions (Jolliffe, 2002):

1. Variables are linearly related to each other,
2. Data are interval scaled,
3. The rating given to any one variable (called factor loading) is partially the result of the influence of other variables.

Depending on the purpose of factor analysis, Principal Component Analysis (PCA) or Common Factor Analysis (CFA) is generally used as analysis model. The former is applied when a survey purposes to reduce a large number of initial variables into a possibly small number of variables for forecasting while the latter is used when a survey aims to find out correlations among variables (Parasuraman et al., 2004). For selecting suitable variables one of the correlation methods is calculating the correlation matrix. These correlation matrixes show the relation between variables and lack of relations with others. KMO (*Kaiser-Meyer-Olkin* measure of sampling adequacy) method can be used for suitable determination and reorganization of data output. There are different factor relations methods like *Varimax*, *Oblimin*, *Quartimax*, *Equamax* and *Promax* that can be used in this factor analysis. But maximum likelihood of factor analysis is being performed by Varimax rotation.

Explanatory Factor Analysis (EFA) can be used enormously in various sectors, various cross cultural studies. Debata et al. (2012) has developed a construct for medical tourism service quality in India using factor analysis technique. The various practices for current occupational health and safety (OHS) standards in industries were extracted using factor analysis (Beriha et al., 2011). The factor analysis technique also used in industrial sector other than social sciences. Ebiringa (2011) applied factor analysis method to find an optimal-mix of interactive factors that would optimize the result of decision to apply information communication technology (ICT) to manufacturing processes. For the location decision of new manufacturing plant and discovering an industrial cluster in Japan, an exploratory factor analysis was performed (Kadokawa, 2011). Zakuan et al., (2010) found out a seven-factor measurement model for TQM constructs which was a good fit and the model was valid and reliable for Malaysia and Thailand automotive industries. Rad et al. (2011) proposed FA technique to identify the most effective activities for selecting a supplier. They aim was to introduce an application of factor analysis for illuminating and classifying supplier selection activities. In the present context, EFA technique has been explored in order to identify the most effective dimensions (factors) towards assessing agility.

In the current research, using SPSS Software Package (Version 16.0) and exploring principal components analysis estimation method, *Varimax* factor rotation and KMO method (suitable recognition and determination of data output), factor analysis has been performed.

2.2.5 Case Study

By library and field researches for determining effective factors explaining organizational agility, the conceptual model has been prepared and considered as an analysis base. Critical analysis of literature reveals a gamut of dimensions and variables responsible for various agile practices in Indian industries. The main objective of this study is to explore effective factors on organizational agility by surveying construct validity of the conceptual organizational agility model through statistical analysis.

1 Questionnaire Survey

To define the effective variables on organizational agility, on the base of the conceptual model, a questionnaire has first been compiled. Firstly eight different questionnaire drafts have been developed. The preliminary questionnaires have been pilot tested.

a. Pilot testing has been conducted before the questionnaire has been used for actual data collection; the eight different questionnaire set have been tested and validated to assure understanding and meanings of presented concepts, clarity of statements, and adequacy of the representation of the basic variable categories. Such verification process has been made through the advisors with research background, chief executive managers and quality management experts of industry included in this study. Based on the result from the pilot test, four questions have been omitted from the questionnaire.
b. The selected questionnaires have been reviewed by managers of several industrial companies, extensive literature review, production managers, quality engineers, consultants.
c. In the third stage, a concrete questionnaire set has been finalized. This process has been continued until all questions in the four questionnaires are unambiguous, appropriate and acceptable to respondents concerned with the implementation. It consisted of five-point Likert scale anchored at (1) 'Very Low', (2) 'Low', (3) 'Medium', (4) 'High', and (5) 'Very High' (Table 2.8).

2 Data Collection

As a case study this survey has been conducted in an Indian automobile industry, one of the largest automotive manufacturing companies in eastern part of India.

The questionnaire used in this study has been distributed to employees including production managers, quality engineers, and workers. Respondents have been requested to indicate their level of perception for each item. The questionnaire of this study has been designed on the basis of *Multi-Dimension Measurement*. It uses a 5-point Likert Scale to measure each answer with 5 being "Very High" and 1 being "Very Low" (Yang and Li, 2002; Tseng and Lin, 2011). A higher point represents a higher degree of agreement, and vice versa. The survey has been conducted through different modes of collecting responses over a period of four months (March 2012–June 2012). Therefore, questions need to be exceptionally clear and easy to respond for this type of questionnaire successfully. The researcher themselves conducted the interview. A total of 375 questionnaires have been sent and 335 responses (89%) have been received.

Responses have been screened based on completeness, rational scoring and adherence to scale and finally, 325 responses (86%) have been considered for further analysis.

3 Results and Discussions

The useful data have been filtered out for further statistical analysis to meet the research objectives. In this study, exploratory factor analytical techniques (EFA) have been adopted to assess the significant entities/dimensions affecting agility of the said organization.

The Factor Analysis (FA) is a data and variable reduction technique, which attempts to partition a given set of variables into groups of maximally correlated variables (Rad et al., 2011). FA helps to convert a large number of variables into a smaller number of variables, called factors, which capture as much information as possible from the original data set (Parasuraman et al., 2004). The useful responses have been tested to examine the validity and reliability of the scale to obtain a quantitative and statistically proven identification of the responses. Factor analysis of responses has been performed using SPSS 16.0. The factor analysis uses principal component extraction method followed by *VARIMAX* rotation. In the initial application, the number of variables has been reduced from 65 to 41. In the second application, these 41 variables have been classified under 13 dimensions based on their factor-loading score (Table 2.9). The items that failed to get loaded more than 0.6 (threshold) have not been considered for further analysis. They refer to the variables V1, V2, V5, V6, V9, V10, V12, V14, V17, V18, V19, V22, V26, V30, V36, V37, V38, V41, V42, V44, V56, V58, V60 and V61.

Since Cronbach's alpha is usually suitable indicator for measuring reliability of measurement tool and internal consistency among its elements. Therefore, questionnaire reliability used in the research has been evaluated by alpha Cronbach. The value of alpha for all dimensions has been obtained as 0.925, which has been found well above the acceptable value of 0.70 for demonstrating internal consistency of the established scale (Nunnally, 1988).

Collected data have been analyzed using PCA of factor analysis (Lee and Lee, 2011). Principal Component Analysis (PCA) is a technique, which reduces the number of variables with an attempt to eliminate the interrelated variables by transforming the system into a smaller system with fewer number of correlated variables called principal components (PCs)/or factors (Jolliffe, 2002; Tziakas et al., 2007). Factor values need to be rotated in order to interpret the solution set more easily (Ocal et al., 2007). After factor rotation, variables need to be loaded maximally to only one factor and minimally to the remaining factors (Field, 2005). Percentage of total variance explained has been obtained as 61.7%, which has been found acceptable for the principal component *VARIMAX* rotated factor-loading procedure (Johnson and Wichern, 2002). The Kaiser–Meyer–Olkin (KMO>0.6) and Bartlett's test of sphericity ($p < 0.05$) statistics have been used to test empirically whether the data have been likely to factor well (Bikker and Thompson, 2006; Kaiser, 1974). The value of KMO has been found to be 0.650; hence it has been concluded that the matrix has not suffered from multi-co linearity or singularity. The result of Bartlett's test of sphericity has showed that it is highly significant (sig. = 0.000), indicating that the factor analysis is correct and suitable for testing multidimensionality (Othman and Owen, 2001). Therefore, statistical tests have showed that the dimensions of instruments have been seemed likely to factor well and the questionnaire has been made multi-dimensional.

The instrument consists of 41 variables that have been classified into 13 dimensions defined as: Cross Border Collaboration, Information Management Agility, Product Design Flexibility, Re-configurability of Manufacturing System, Agility in Institutional Framework, Production Organizing Agility, Team Building Agility, Customer Demand Information Agility, Product Design Speed, Speed of Manufacturing, Manufacturing Flexibility, Inter-Organization Co-ordination and Speed of Information shown in Table 2.10.

Table 2.11 shows the percentage of variation explained by factor analysis with *VARIMAX* rotation. Cross border collaboration has been found to be the most important factor, whereas Speed of information, the least important factor.

Cross border collaboration and Information management agility are the crux which affects most of the agility factors of a manufacturing industry followed by Product design flexibility, Re-configurability of manufacturing system and Agility in institutional framework. Production organizing agility etc. is the sixth ranked factor followed by Team building agility, Customer demand information agility. The path to agile manufacturing paradigm can be paved by Product Design speed and Speed of manufacturing which play important role in agile concept deployment whereas, Manufacturing flexibility, Inter-organization co-ordination and Speed of information occupied the bottom of the pyramid but still has some say for implementing agile manufacturing concept.

The mean of the loaded variables for the responses has been indicated in Fig. 3.3. It has been found that V34 (Displacement compatibility) has the highest average mean value of 4.4 followed by V35 (Displacement of process variety) with Average Mean Value 4.26. Therefore, displacement compatibility plays important role for agile approaches. It helps to enhance re-configurability of manufacturing system. It is necessary for grouping of parts and products into families to reduce work-in-process variety and shorten set-up time at the time of reconfiguring the manufacturing enterprise. This is followed by V20 (The serrating degree of the product) and V65 (Utilization of electronic data exchange system (EDI)) with same average mean 4.23.The serrating degree of the product is the most important form of standardization as requirements of product personalization. Owing to the highly developed material products seriation are paid more attention towards enterprise competition. By utilizing electronic data exchange system the information about market condition and the operational data can speedily be transmitted which enables the organization to sustain in the competitive market scenario. The least average mean has been found to be 3.30 for V4 (Frequency of enterprise modeling).The Enterprise Modeling is the representation of a part or of the set of enterprise at a global level. It allows describing the running of the enterprise in terms of objectives, structure, functionalities, evolution and relationship with customers and suppliers. It supports in modeling of various new concepts as agile manufacturing, virtual enterprise or extended enterprise.

2.2.6 Concluding Remarks

Based upon the aforesaid study, different agile dimensions have been identified in relation to a case industry. The study exhibits existence of 41 different agile entities that can be adopted by industries/supply chain to enhance their market competitiveness. These entities have been categorized into thirteen impact areas namely, *cross border collaboration*, *information management agility*, *product design flexibility*, *reconfigurability of manufacturing system*, *agility in institutional framework*, *production organizing agility*, *team building agility*, *customer demand information agility*, *product design speed*, *speed of manufacturing*, *manufacturing flexibility*, *inter-organization co-ordination* and *speed of information*. In this study, all the agility practices have been loaded significantly on their corresponding constructs at the 0.06 level. This demonstrates a good-fit model. To achieve overall firm's agility, this model can be considered as a key tool. The results provide insights into the factors that influence the choice of the agile manufacturing strategies for improving operations, and the results that can be obtained. The organization can use this agile assessment procedure as a test kit for periodically monitoring existing agility level. This kind of agility assessment exercise would enable the organization to survive and grow in competitive business environment. The approach may enable improvement of strategic agile position of the said organization. The methodology adapted here can also be applied to manufacturing as well as service organizations with a view to make them agile. To the authors' knowledge, this is an empirical survey of agility using data from a large-scale Indian industry. The model incorporates a wide perspective on entities related to agile manufacturing industry.

The analysis requires much background information about the benefits of the agile methods, practices and tools in different situations. Therefore, a high quality agile toolbox would help in future agile assessments.

Apart from understanding and aligning agile dimensions, research can be extended to compute agility extent for the said enterprise. The computed agility degree (agility index) may be compared with predefined agility measurement scale to assess organizational current agile scenario. The study may further be extended to identify and improve different agile barriers. The computed agility index may be utilized for benchmarking of agile enterprises which is highly important in managerial context. Attempts have been made to address aforesaid issues in next subsequent chapters.

Table 2.8: Questionnaire: Perception of industry personnel: Assignment of performance rating against 3rd level evaluation indices

Scale to be used: 5 Member Linguistic Scale: Very High (VH), High (H), Medium (M), Low (L), and Very Low (VL)

1st Level Index	2nd Level Index	3rd Level Index	Ratings
Organization management agility	Agility in institutional framework	Existence of a well-defined system architecture to promote agility	
		Establishing a physically distributed manufacturing architecture precisely in a stable state	
		Ability to rapidly set up the entire organization adaptable to new method of operation	
		Frequency of enterprise modeling	
		Adaptability of best practices in other organizations by benchmarking	
		Application of business process reengineering (BPR) for reinventing and reengineering the organization	
		Good housekeeping practices	
	Team building agility	Speed of the team building	
		Formation of team across company borders	
		Use of interdisciplinary teams by organizing themselves to take the advantages of market opportunities	
		Empowerment of personnel to resolve customer and process related problems	
	Production organizing agility	Adoption of concurrent engineering (CE)	
		Identification of market for new products	
		Degree of innovation and new product development (NPD) techniques that calls for uniqueness and novelty in the product	
		Degree of automation applied to manufacturing.	
		Degree of automation in inspection system	
Product design agility	Product design flexibility	Management's interest towards evolving new product models	
		Extent of inculcation of innovation into product design	
		Degree of recycling orientation during product design	
		The serating degree of the product	
		Degree of standardization of the commodity	

		Speed at which suppliers are being developed for new products	
		Similarity of product structure	
		Preparedness of the management to invest on latest design techniques like RP and CAD/CAM	
		Products incorporated with modular design	
	Customer demand information agility	Swiftness in obtaining demand information	
		Extent of customer satisfaction orientation	
		The proportion of information processing time in product period	
	Product design speed	Time for product development cycle time	
		Design selection that minimizes the no. of parts	
		Design lead time	
Processing manufacture agility	Reconfigurability of manufacturing system	Capacity of packaging the integrated unit in a modular fashion	
		Supplement tool displacement	
		Displacement compatibility	
		Displacement of process variety	
		Design for manufacturing and assembly	
	Speed of manufacturing	Period of both inter-lot and in-lot set up time	
		Speed of material handling systems	
		Leadership in the use of current technology	
		The overall period of product manufacture	
		The proportion of manufacture period in products period	
	Manufacturing flexibility	Flexible material handling equipment	
		The universal degree of equipment	
		The scalable degree of equipment	
		Flexibility of equipment	
Partnership formation capability	Inter-organization coordination	Degree of enterprise integration	
		Degree of cooperation with other enterprise	
		Reliable network of suppliers	
		Adoption of SCM concepts for enhancing the outsourcing efficieny	
	Cross-border collaboration	Strategic relationship with customers	
		Speed of development of products jointly with other	

		companies	
		Trust based relationship	
		Speed of partnership formation	
		Formation of virtual manufacturing enterprise (VME)	
Integration of information system	Information management agility	Interoperability and networking	
		Ability to exchange information	
		Utilizing artificial intelligence (AI) with computer aided design	
		Correctness and accuracy of data	
		Maintenance information system	
		Companywide integration of information system	
		IT application to eliminate paper work	
		Adoption of multimedia technology	
	Speed of information sharing	Information and network utilization rate	
		Utilization of electronic data exchange system (EDI)	

Table 2.9: Factor loading scores

Variables	Variable No.	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
Strategic relationship with customers	V50	0.695												
Speed of development of products jointly with other companies	V52	0.763												
Trust based relationship	V52	0.784												
Speed of partnership formation	V53	0.764												
Collaboration among partners	V54	0.630												
Formation of virtual manufacturing enterprise (VME)	V55	0.708												
Ability to exchange information	V57		0.658											
Correctness and accuracy of data	V59		0.675											
IT application to eliminate paper work	V62		0.652											
Adoption of multimedia technology	V63		0.639											
The serating degree of the product	V20			0.645										
Degree of standardization and commonality	V21			0.616										
Similarity of the product structure	V23			0.646										
Preparedness of the management to invest on latest design techniques like RP and CAD/CAM	V24			0.619										
Products incorporated with modular design	V25			0.655										
Capability of packaging the integrated unit in a modular fashion	V32				0.688									
Supplement tool displacement	V33				0.617									
Displacement compatibility	V34				0.693									
Displacement of process variety	V35				0.716									
Ability to rapidly set up the entire organization adaptable to new method of operation	V3					0.610								
Frequency of enterprise modeling	V4					0.641								
Good housekeeping practices	V7					0.655								
Identification of market for new products	V13						0.646							
Degree of automation applied to manufacturing	V15						0.635							
Degree of automation in inspection	V16						0.674							

systems														
Speed of the team building	V8							0.693						
Empowerment of personnel to resolve customer and process related problems	V11							0.701						
Extent of customer satisfaction orientation	V27								0.700					
The proportion of information processing time in product period	V28								0.796					
Time for product development cycle time	V29									0.644				
Design lead time	V31									0.710				
Leadership in the use of current technology	V39										0.664			
The overall period of product manufacture	V40										0.640			
The universal degree of equipment	V43											0.769		
Equipment flexibility	V45											0.672		
Degree of cooperation with other enterprise	V47												0.753	
Reliable network of suppliers	V48												0.754	
Information and network utilization rate	V64													0.636
Utilization of electronic data exchange system	V65													0.618

Table 2.10: Dimensions of agility

Dimensions	Variables	Variable No.
Cross boarder collaboration	Strategic relationship with customers	V50
	Speed of development of products jointly with other companies	V52
	Trust based relationship	V52
	Speed of partnership formation	V53
	Collaboration among partners	V54
	Formation of Virtual Manufacturing Enterprise (VME)	V55
Information management agility	Ability to exchange information	V57
	Correctness and accuracy of data	V59
	IT application to eliminate paper work	V62
	Adoption of multimedia technology	V63
Product design flexibility	The serating degree of the product	V20
	Degree of standardization and commonality	V21
	Similarity of the product structure	V23
	Preparedness of the management to invest on latest design techniques like RP and CAD/CAM	V24
	Products incorporated with modular design	V25
Reconfigurability of the manufacturing system	Capability of packaging the integrated unit in a modular fashion	V32
	Supplement tool displacement	V33
	Displacement compatibility	V34
	Displacement of process variety	V35
Agility in institutional framework	Ability to rapidly set up the entire organization adaptable to new method of operation	V3
	Frequency of enterprise modeling	V4
	Good housekeeping practices	V7
Production organizing agility	Identification of market for new products	V13
	Degree of automation applied to manufacturing	V15
	Degree of automation in inspection systems	V16
Team building agility	Speed of team building	V8
	Empowerment of personnel to resolve customer and process related problems	V11
Customer demand information agility	Extent of customer satisfaction orientation	V27
	The proportion of information processing time in product period	V28
Product design speed	Time for product development cycle time	V29

	Design lead time	V31
Speed of manufacturing	Leadership in the use of current technology	V39
	The overall period of product manufacture	V40
Manufacturing flexibility	The universal degree of equipment	V43
	Flexibility of equipment	V45
Inter-organization cooperation	Degree of cooperation with other enterprises	V47
	Reliable network of suppliers	V48
Speed of information	Information and network utilization rate	V64
	Utilization of electronic data exchange system	V65

Table 2.11: Percentage of variation explained by factor analysis

Dimensions	Percentage of commonality variance explained	Ranking order
Cross boarder collaboration	8.57	1
Information management agility	6.91	2
Product design flexibility	5.81	3
Reconfigurability of manufacturing system	5.50	4
Agility in institutional framework	4.54	5
Production organizing agility	4.49	6
Team building agility	4.40	7
Customer demand information agility	4.31	8
Product design speed	3.86	9
Speed of manufacturing	3.81	10
Manufacturing flexibility	3.42	11
Inter-organization cooperation	3.27	12
Speed of information	2.81	13

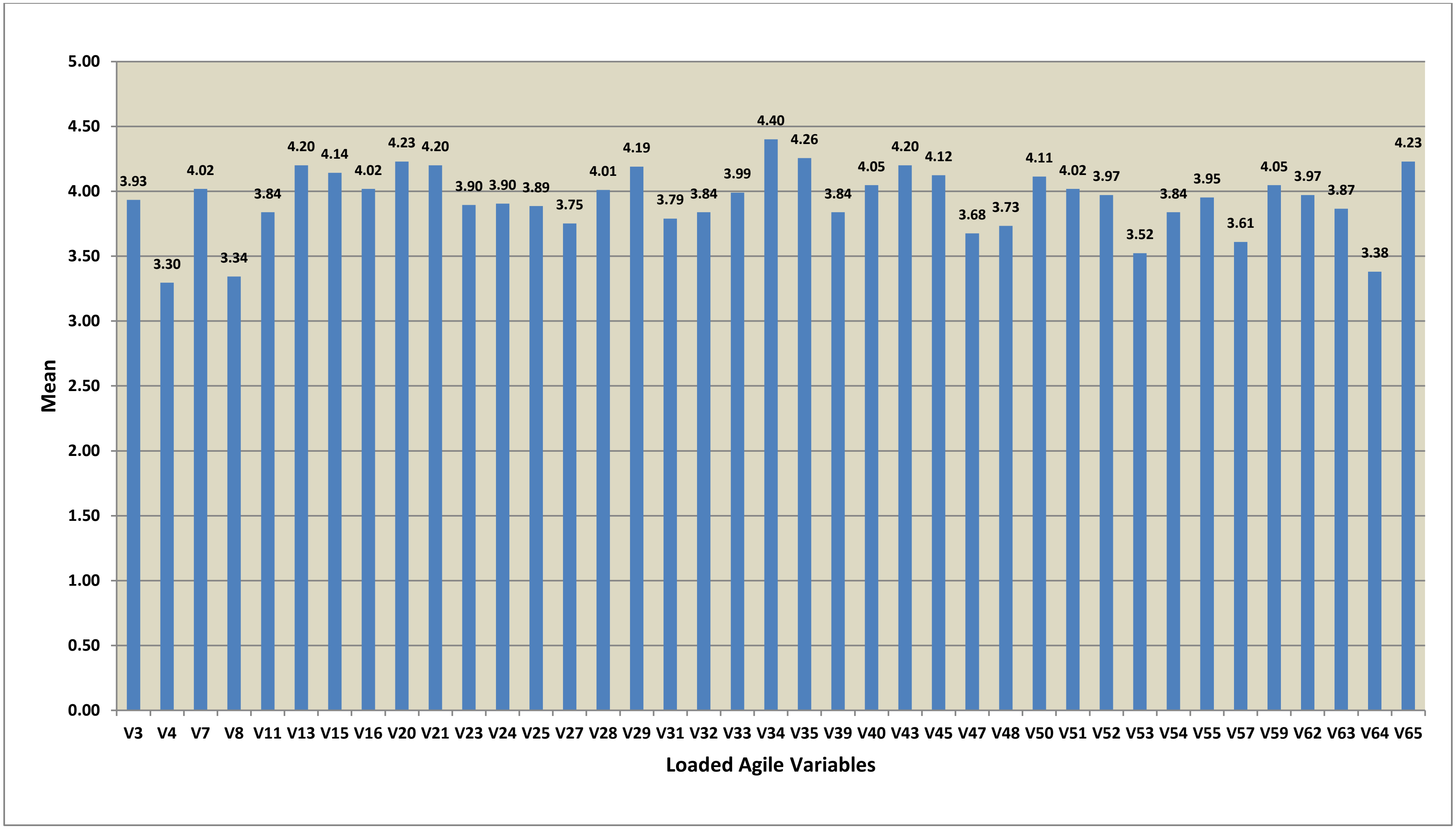

Fig 2.3: Average perception of agile entities

CHAPTER 3

DEVELOPMENT OF AGILITY APPRAISEMENT MODULES IN INDUSTRIAL SUPPLY CHAIN

3.1 Agility Appraisement in Fuzzy Context

This section attempts to develop different agility appraisement modules in fuzzy environment. Incorporation of the theory of Generalized Fuzzy Numbers (GFNs), Interval-Valued Fuzzy Numbers (IVFNs) set theory has been presented here to facilitate agility appraisement decision-making.

3.1.1 Agility Appraisement using GTFNs

3.1.1.1 Overview

The objective of this part of study is to contribute important insights to the extant body of knowledge in Agile Supply Chain (ASC). An approach based on Generalized Trapezoidal Fuzzy Numbers (GTFNs) set has been adopted for agility appraisal in supply chain. An Agile Supply Chain (ASC) is frequently considered as a stimulant for dominant competitive advantage. Complexity and vagueness involved in agility evaluation process must be considered precisely for agility estimation for an ASC system. Fuzzy set theory has been efficiently explored in order to assess the contributions of complicated agility capabilities in an ambiguous fuzzy environment. Application of the said approach as a Decision Support System (DSS) evidently would help the management practitioners to conduct gap analysis between existing agility level and the desired one; and also provides reliable information for decision-making.

3.1.1.2 State of Art Understanding and Problem Formulation

Supply Chain Agility is an operational strategy focused on inducing velocity, flexibility, and responsiveness in the supply chain. A supply chain is the process of forwarding goods from the customer order through the raw material stage, supply, production, and distribution of products to the customer side. All organizations follow supply chains of varying degrees, depending upon the volume of the organization and the type of product being manufactured. These networks obtain supplies and components, transform these materials into finished products and then distribute them to the customer [Source: *http://rockfordconsulting.com/supply-chain-agility.htm*]

The Agility Forum (1994) has defined 'agility' as the ability of an organization to thrive in a continuously changing, unpredictable business environment. Simply put, an agile firm has designed its organization, processes and products such that it can respond to changes in a useful time frame.

Edmund et al. (2001) reported that despite the obvious benefits of agility, firms that operate in complex environments such as international markets face challenges in implementing the measures necessary to increase their agility. These challenges stem from the expense associated with the complex operations and management structures necessary to support the desired attributes. Moreover, it may be difficult for this firm to promptly react to changes in demand. Hence, unless the firm is willing to significantly increase it's administrative and logistics costs (e.g. for coordinating all parts of its value and supply chains), it may be forced to take counter-agile actions in order to remain competitive, and limit its vulnerability in the marketplace. The authors proposed a theoretical construct linking elements of uncertainty with aspects of agility, pointing out the two-edged nature of the requisite capabilities. Yusuf et al. (2004) discussed the nature of an agile supply chain and explored some of its attributes and capabilities. The attributes included internet based collaboration, a significant amount of sales turnover and profit from virtual business, open leverage of capabilities within networks of companies and manufacturing, rather than outsourcing and marketing alliances. Kumar et al. (2006) developed a conceptual framework for implementing and managing supply chain flexibility in supply chain organizations. The framework suggested that supply chain flexibility should be implemented and managed using a three-stage approach: required flexibility identification, implementation and shared responsibility, and feedback and control.

Apart from selecting agile criteria and developing conceptual framework (Ramesh and Devadasan, 2007; Sherehiy et al., 2007; Giachetti et al., 2003) to model agile supply chains; the degree of agility that the AMS possess has been viewed as a major area of concern. A strong mathematical background is indeed required to assess and estimate agility extent. This may help the industries to understand the status of present agile practices, identification of agile barriers and finding scope for future improvement. Agility index may also help for benchmarking of agile industries. Unfortunately, no measurement scale exists to reflect the complexity of this phenomenon (Audrey, 2011).

'Agility' being a hypothetical concept exclusively subjective in nature; proper (numeric) data cannot be obtained against evaluation criterions related to priority weight as well as performance rating. Thus, to convert a subjective managerial aspect into a logical mathematic base, application of fuzzy logic has been proposed. The use of fuzzy numbers (instead of Likert scale) against inconsistent information is advantageous. The evaluation module proposed here has been based on well-established equations (Lin et al., 2006a, b) already available in literature.

Most of the agility measurements are described subjectively by linguistic terms, which are characterized by ambiguity and multi-possibility. Thus, the scoring of the existing techniques can always be criticized, because the scale used to score the agility capabilities has limitations.

There is no methodology and tools for introducing and implementing such a complex and dynamic interactive system which incorporate both quantitative and qualitative attributes as agile supply chains (Lin et al., 2006a, b). In this context, Fuzzy logic provides a useful tool to deal with problems in which the attributes and phenomena are imprecise and vague in nature (Zadeh, 1965).

During agility evaluation, frequently the data cannot be analyzed by standard statistical methods, either because there are numerous missing records, or because the data are in the form of qualitative rather than quantitative measures.

In many cases, the information contained in these databases is undervalued and underutilized because the data cannot be easily accessed or analyzed. Some databases have grown so large that even the system administrators do not always know what information might be represented or how relevant it might be to the questions at hand. Data sets commonly contain some uncertain, particularly incompleteness and inconsistency. One example is a distributed information environment, where data sets are generated and collected from different sources, and each source may have different constraints. This can lead to different interrelationships among the items, thus imposing vagueness on the data set. Recent years have witnessed many efforts on discovering fuzzy associations, aimed at coping with fuzziness in knowledge representation and decision support process. Therefore, the necessity of applying Fuzzy Logic in data mining is due to the following (Yanfang and Fu, 2008):

1. One is that fuzziness is inherent in many problems of knowledge representation, and the other is that high-level managers or complex decision processes often deal with generalized concepts and linguistic expressions, which are generally fuzzy in nature.
2. Moreover fuzziness may prevail in many other association cases in which impression, matching, similarity, implication, partial truth or the like is present.
3. The modeling of imprecise and qualitative knowledge, as well as the transmission and handling of uncertainty at various stages are possible through the use of fuzzy sets.
4. Fuzzy logic is capable of supporting to a reasonable extent, human type reasoning in natural form.

Jain and Benyoucef (2008) presented an approach to model agility and introduced *Dynamic Agility Index* through fuzzy intelligent agents. The proposed approach concentrated on the application of linguistic approximating, fuzzy arithmetic and agent technology was developed to address the issue of agility measuring, stressing the multi-possibility and ambiguity of agility capability measurement. They applied *Fuzzy Association Rule Mining* incorporating fuzzy framework coupled with rules mining algorithm to support the decision makers by enhancing the flexibility in making decisions for evaluating agility with both tangibles and intangibles characteristics. Yang and Li (2002) suggested the establishment of an agility evaluation index system of mass customized (MC) product manufacturing based on the characteristics of MC product manufacturing as well as the requirements of agility manufacturing.

Tsourveloudis and Valavanis (2002) proposed, a knowledge based framework for the measurement and assessment of manufacturing agility. In order to calculate overall agility of an enterprise, a set of quantitatively defined agility parameters were proposed and grouped into production, market, people and information infrastructures. The combined, resulting, measure incorporated the individual and grouped infrastructure agility parameters and their variations into one calculated value of the overall agility. The necessary expertise used to quantitatively determine and measure individual agility parameters was represented via fuzzy logic terminology that allows for human-like knowledge representation and reasoning.

Lin et al. (2006a, b) developed a fuzzy agility index (FAI) based on agility providers using fuzzy logic. This evaluation demonstrated that the method could provide analysts with more informative and reliable information for decision-making. Tsai et al. (2008) used fuzzy-logic Quality Function Deployment (QFD) approach in order to align agile drivers, capabilities and providers to achieve agility. Wang (2009) proposed a suitable agile system for implementing MC. He highlighted a MC manufacturing agility evaluation approach based on the concepts of TOPSIS through analyzing the agility of organization management, product design, processing manufacture, partnership formation capability and integration of information system. Seyedhoseini et al. (2010) developed an approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for measurement of agility in supply chain. The said procedure was efficiently been applied to a large scale automobile manufacturing company in Iran.

Vinodh et al. (2010a; 2011) attempted to assess the agility level of an organization using a multi-grade fuzzy approach. During this research, an agility index measurement model containing twenty criteria incorporated with the multi-grade fuzzy approach was designed and proposals for enhancing the agility level of this company were derived. In another paper, (Vinodh et al.; 2010b) modeled a total agile design system (TADS) while implementing in a traditional manufacturing organization following mass production-based practices. A scoring model was used for measuring agility before and after implementation of TADS.

Kaveh et al. (2011) proposed a hybrid approach in order to measure the relative efficiency of agility in supply chains. First, a conceptual model including capabilities and providers of agility in supply chains was represented. Then, a supply chain was made associated to a Decision Making Unit (DMU) which consumed providers of agility to produce capabilities of agility. Fuzzy

Data Envelopment Analysis (FDEA) was applied in their work. Yauch (2011) constructed a quantitative, objective metric for agility performance that assessed agility as a performance outcome, capturing both organizational success and environmental turbulence, and applicable to manufacturing organizations of all types.

Tseng and Lin (2011) suggested an agility development method for dealing with the interface and alignment issues among agility drivers, capabilities and providers using the QFD relationship matrix and fuzzy logic. A Fuzzy Agility Index (FAI) for an enterprise composed of agility capability ratings and a total relation-weight with agility drivers was developed to measure the agility level of an enterprise.

In the present study, extent of agility evaluation in supply chain has been viewed as a Multi-Criteria Decision Making (MCDM) problem. Agile providers, agile criteria and agile attributes are interconnected in a logical manner and the degree of effective interaction enhances supply chain agility. Most of the agile criteria being qualitative in nature; the extent of successful performance of each individual criterion is judged by the experts called Decision-Makers (DMs) which may vary depending on individuals' perception as well as viewpoint. Moreover, it becomes difficult for the DMs to assign exact numeric score against performance rating of various criteria-attributes. The degree of importance (priority weights) of various criteria also differs due to individuals' discretion. This kind of uncertainty in decision making process can fruitfully be tackled by using fuzzy logic. In exploration of fuzzy set theory in group decision-making process, DMs personal opinion is expressed by linguistic variables which are further converted into corresponding fuzzy numbers. With the help of fuzzy arithmetic operations, aggregated criteria weight and corresponding criteria rating are combined to compute an overall agility assessment index.

Previous researchers have adopted fuzzy based approaches in estimating fuzzy agility index. However, most of the cases, they used triangular fuzzy number (Lin et al., 2006a, b) and corresponding membership functions (MFs). In dealing with agility appraisal in SC, generalized trapezoidal fuzzy numbers may be explored. Not only agility evaluation, the criteria which affect adversely to enrich agility (anti-agile characteristics/ agile barriers) should be identified in which the supply chain must improve to uplift agility level. This requires the concept of fuzzy number ranking. Ranking methodologies of triangular fuzzy number have been well documented in literature and immensely applied in various decision-making arenas. Literature is seemed limited in addressing the procedure for ranking of trapezoidal fuzzy numbers. Motivated by this scope of research, the present study aims to develop a group decision-making procedural hierarchy based on generalized trapezoidal fuzzy numbers sets for agility index appraisement in supply chain. Detailed methodology of the proposed approach has been illustrated while implementing in an empirical study to ensure considerable extent of reliability in such an evaluation process.

3.1.1.3 Conceptual Model for Agility Measurement in Supply Chain

During the past few years, supply chain agility has gained prominence as a competitive weapon in organizational supply chain management. Measurement of agility index is of prime importance to assess existing agility level, to identify various agile barriers and to change strategic concepts in order to improve agility. In this study, supply chain agility has been defined as a measure of the supply chain's ability to efficiently adapt to a rapidly changing competitive environment to provide quality products to the global marketplace. It has been assumed that supply chain agility may be determined mainly by four agile enablers (i) flexibility, (ii) responsiveness, (iii) competency, and (iv) cost (Jain and Benyoucef, 2008; Seyedhoseini et al., 2010). Flexibility comprises of sourcing flexibility, manufacturing flexibility and delivery flexibility. Responsiveness is characterized by sourcing responsiveness, manufacturing responsiveness and delivery responsiveness components. Competency includes the following components: cooperation and internal-external balance, capabilities of human resource and manufacturing competency. Cost aspect includes sourcing cost, manufacturing cost and delivery cost. These sub components are called agile providers (attributes). Agile attributes are characterized by different agile criteria (Cooper, 1993; Sharifi and Zhang, 1999; Christopher and Towill, 2000; Agarwal and Shankar, 2002a, b; Swafford, 2006a, b). The model adopted in the present work has been presented in Table 3.1.

3.1.1.4 The Concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs) Set

By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as a vector shown below.

$\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, and the membership function $a(x): R \to [0,1]$ is defined as follows:

$$a(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x-a_4}{a_3-a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \tag{3.1}$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

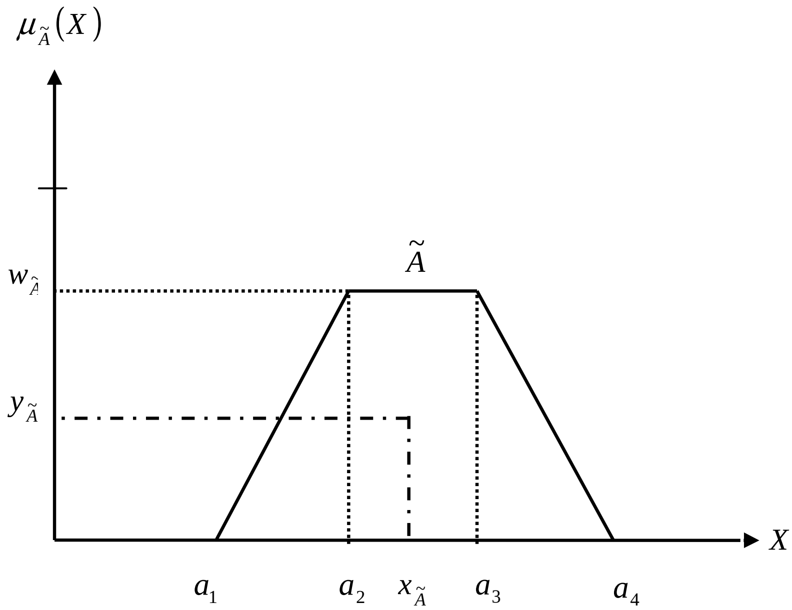

Fig. 3.1 Generalized trapezoidal fuzzy number

The elements of the generalized trapezoidal fuzzy numbers (Fig. 3.1) $x \in R$ are real numbers, and its membership function $a(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.2}$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$\left(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \tag{3.3}$$

$$\tilde{a} \otimes \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right) \otimes \left(b_1, b_2, b_3, b_4; w_{\tilde{b}}\right) =$$
$$\left(a, b, c, d; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \tag{3.4}$$

Here,

$$a = \min\left(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4\right)$$
$$b = \min\left(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3\right)$$
$$c = \max\left(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3\right)$$
$$d = \max\left(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4\right)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = \left(a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right)$$
$$\tilde{a} / \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right) \Big/ \left(b_1, b_2, b_3, b_4; w_{\tilde{b}}\right)$$
$$= \left(a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \tag{3.5}$$

Chen and Chen (2003a, b) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right)$ is $\left(x_{\tilde{a}}, y_{\tilde{a}}\right)$, then:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2\right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases}$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times \left(a_2 + a_3\right) + \left(a_1 + a_4\right) \times \left(w_{\tilde{a}} - y_{\tilde{a}}\right)}{2 \times w_{\tilde{a}}} \tag{3.6}$$

3.1.1.5 The Concept of Comparing and Ranking of Trapezoidal Fuzzy Numbers

Ranking of fuzzy numbers play an important role in risk analysis, decision making, optimization, forecasting etc. Fuzzy numbers must be ranked before an action is taken by a decision maker. (Kumar et al., 2010) proposed a method for the ranking of generalized trapezoidal fuzzy numbers. The proposed approach was based on rank, mode, divergence and spread. This approach provides the correct ordering of generalized and normal trapezoidal fuzzy numbers. Moreover, the approach is very simple and easy to apply in the real life problems.

As given by (Kumar et al., 2010), a trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ is said to be a generalized trapezoidal fuzzy number if its membership function is given by:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{w(x-a)}{(b-a)}, & a \leq x \leq b \\ w, & b \leq x \leq c \\ \dfrac{w(x-d)}{(c-d)}, & c \leq x \leq d. \end{cases} \tag{3.7}$$

Let $\tilde{A} = (a, b, c, d; w)$ be a generalized trapezoidal fuzzy number then,

(i) $\Re(\tilde{A}) = \dfrac{w(a+b+c+d)}{4}$

(ii) $\text{mode}(\tilde{A}) = \dfrac{w(b+c)}{2}$

(iii) $\text{divergence}(\tilde{A}) = w(d-a)$

(iv) $\text{Left spread}\ (\tilde{A}) = w(b-a)$

(v) $\text{Right spread}\ (\tilde{A}) = w(d-c)$

Proposition 1:

Let $\tilde{A} = (a_1, b_1, c_1, d_1; w_1)$ and $\tilde{B} = (a_2, b_2, c_2, d_2; w_2)$ be two generalized trapezoidal fuzzy numbers such that,

(i) $\Re(\tilde{A}) = \Re(\tilde{B})$,

(ii) $\text{mode}(\tilde{A}) = \text{mode}(\tilde{B})$

(iii) $\text{divergence}(\tilde{A}) = \text{divergence}(\tilde{B})$ then

(a) Left spread $(\tilde{A}) >$ Left spread $(\tilde{B})$ *if* $w_1 b_1 > w_2 b_2$

(b) Left spread $(\tilde{A}) <$ Left spread $(\tilde{B})$ *if* $w_1 b_1 < w_2 b_2$

(c) Left spread $(\tilde{A}) =$ Left spread $(\tilde{B})$ *if* $w_1 b_1 = w_2 b_2$

All the results of *Proposition 1* also hold for right spread.

Proposition 2:

Let $\tilde{A} = (a_1, b_1, c_1, d_1; w_1)$ and $\tilde{B} = (a_2, b_2, c_2, d_2; w_2)$ be two generalized trapezoidal fuzzy numbers such that,

(i) $\Re(\tilde{A}) = \Re(\tilde{B})$,

(ii) $\text{mode}(\tilde{A}) = \text{mode}(\tilde{B})$

(iii) $\text{divergence}(\tilde{A}) = \text{divergence}(\tilde{B})$ then

(a) Left spread $(\tilde{A}) >$ Left spread $(\tilde{B})$ *if* Right spread $(\tilde{A}) >$ Right spread $(\tilde{B})$

(b) Left spread $(\tilde{A}) <$ Left spread $(\tilde{B})$ *if* Right spread $(\tilde{A}) <$ Right spread $(\tilde{B})$

(c) Left spread $(\tilde{A}) =$ Left spread $(\tilde{B})$ *if* Right spread $(\tilde{A}) =$ Right spread $(\tilde{B})$

Let $\tilde{A} = (a_1, b_1, c_1, d_1; w_1)$ and $\tilde{B} = (a_2, b_2, c_2, d_2; w_2)$ be two generalized trapezoidal fuzzy numbers then use the following steps to compare $\tilde{A}$ and $\tilde{B}$.

<u>Step 1</u>: Find $\Re(\tilde{A})$ and $\Re(\tilde{B})$

Case 1: If $\Re(\tilde{A}) > \Re(\tilde{B})$ then $\tilde{A} \succ \tilde{B}$

Case 2: If $\Re(\tilde{A}) < \Re(\tilde{B})$ then $\tilde{A} \prec \tilde{B}$

Case 3: If $\Re(\tilde{A}) = \Re(\tilde{B})$ then go to step 2.

<u>Step 2</u>: Find $\text{mode}(\tilde{A})$ and $\text{mode}(\tilde{B})$

Case 1: If $\text{mode}(\tilde{A}) > \text{mode}(\tilde{B})$ then $\tilde{A} \succ \tilde{B}$

Case 2: If $\text{mode}(\tilde{A}) < \text{mode}(\tilde{B})$ then $\tilde{A} \prec \tilde{B}$

Case 3: If $\text{mode}\left(\tilde{A}\right) = \text{mode}\left(\tilde{B}\right)$ then go to step 3.

Step 3: Find $\text{divergence}\left(\tilde{A}\right)$ and $\text{divergence}\left(\tilde{B}\right)$

Case 1: If $\text{divergence}\left(\tilde{A}\right) > \text{divergence}\left(\tilde{B}\right)$ then $\tilde{A} \succ \tilde{B}$

Case 2: If $\text{divergence}\left(\tilde{A}\right) < \text{divergence}\left(\tilde{B}\right)$ then $\tilde{A} \prec \tilde{B}$

Case 3: If $\text{divergence}\left(\tilde{A}\right) = \text{divergence}\left(\tilde{B}\right)$ then go to step 4

Step 4: Find $\text{Left spread}\left(\tilde{A}\right)$ and $\text{Left spread}\left(\tilde{B}\right)$

Case 1: $\text{Left spread}\left(\tilde{A}\right) > \text{Left spread}\left(\tilde{B}\right)$

i.e., $w_1 b_1 > w_2 b_2$ then $\tilde{A} \succ \tilde{B}$ (From proposition 1)

Case 2: $\text{Left spread}\left(\tilde{A}\right) < \text{Left spread}\left(\tilde{B}\right)$

i.e., $w_1 b_1 < w_2 b_2$ then $\tilde{A} \lhd \tilde{B}$ (From proposition 1)

Case 3: $\text{Left spread}\left(\tilde{A}\right) = \text{Left spread}\left(\tilde{B}\right)$

i.e., $w_1 b_1 = w_2 b_2$ then go to step 5. (From proposition 1)

Step 5: Find w_1 and w_2

Case 1: If $w_1 > w_2$ then $\tilde{A} \succ \tilde{B}$

Case 2: If $w_1 < w_2$ then $\tilde{A} \prec \tilde{B}$

Case 3: If $w_1 = w_2$ then $\tilde{A} \sim \tilde{B}$

However, this technique does not provide representative ranking value corresponding to a particular fuzzy number. Moreover, the method becomes tedious for comparing large fuzzy numbers set. Therefore, the study also explores the concept of ranking fuzzy numbers with 'maximizing set and minimizing set' as documented in literature. According to Chen (1985), Suppose there are n generalized fuzzy numbers $A_1, A_2, ..., A_n$ with trapezoidal membership functions $A_i = (c_i, a_i, b_i, d_i; w_i),\ i = 1, 2, ..., n.$

The trapezoidal membership function of generalized fuzzy number A_i is given by:

$$f_{A_i}(x) = \begin{cases} w_i(x - c_i)/(a_i - c_i), & c_i \le x \le a_i, \\ w_i, & a_i \le x \le b_i, \\ w_i(x - d_i)/(b_i - d_i), & b_i \le x \le d_i \\ 0, & otherwise. \end{cases} \quad (3.8)$$

The membership functions of maximizing set M and minimizing set G are given by,

$$f_M(x) = \begin{cases} w\left[\dfrac{(x - x_{\min})}{(x_{\max} - x_{\min})}\right]^k, & x_{\min} \le x \le x_{\max}, \\ 0, & otherwise. \end{cases} \quad (3.9)$$

$$f_G(x) = \begin{cases} w\left[\dfrac{(x - x_{\max})}{(x_{\min} - x_{\max})}\right]^k, & x_{\max} \le x \le x_{\min}, \\ 0, & otherwise. \end{cases} \quad (3.10)$$

Here $x_{\min} = \inf S,\ x_{\max} = \sup S,\ S = \cup_{i=1}^{n} S_i,\ S_i = \{x|\ f_{A_i}(x) > 0\},\ w_i = \sup_x f_{A_i}(x),\ w = \inf w_i.$ When $(k = 1)$ the membership function is linear; $(k = 2)$ the membership function is risk prone and $\left(k = \dfrac{1}{2}\right)$ the membership function is risk-averse. In general, these three cases cover the three types of preference-fair, adventurous, conservative-of human being (decision-maker).

The total utility of A_i computed as:

$$U_T(i) = \{U_M(i) + w - U_G(i)\}/2 \quad (3.11)$$

(i) When $k = 1$

$$U_T(i) = \frac{w_i w}{2}\left[\frac{(d_i - x_{\min})}{\{w_i(x_{\max} - x_{\min}) - w(b_i - d_i)\}} + \frac{1}{w_i} - \frac{(x_{\max} - c_i)}{\{w_i(x_{\max} - x_{\min}) + w(a_i - c_i)\}}\right],\ i = 1,2,...,n; \quad (3.12)$$

(ii) When $k = 2$

$$U_T(i) = \frac{1}{2}\left[\begin{array}{l} w_i\left\{x_{\min} - d_i + \frac{w_i(x_{\max} - x_{\min})^2}{(2w(b_i - d_i))} + (x_{\max} - x_{\min}) \times \frac{\{w_i^2(x_{\max} - x_{\min})^2 + 4ww_i(b_i - d_i)(x_{\min} - d_i)\}^{\frac{1}{2}}}{2w(d_i - b_i)(b_i - d_i)}\right\} \\ + w - \left\{w_i\left(x_{\max} - c_i + \frac{w_i(x_{\max} - x_{\min})^2}{2w(a_i - c_i)} - \frac{(x_{\max} - x_{\min})(w_i^2 - (x_{\max} - x_{\min})^2 + 4ww_i(a_i - c_i)(x_{\max} - c_i))^{\frac{1}{2}}}{2w(a_i - c_i)}\right)\right\} \end{array}\right],$$

$i = 1, 2, \ldots, n;$

(3.13)

(iii) When $k = \frac{1}{2}$

$$U_T(i) = \frac{1}{2}\left[\begin{array}{l} w^2(b_i - d_i) + w\{w^2(b_i - d_i)^2 + 4w_i^2(x_{\max} - x_{\min})(d_i - x_{\min})\}^{1/2} \\ + 2ww_i(x_{\max} - x_{\min}) + w^2(a_i - c_i) - w\{w^2(a_i - c_i)^2 + 4w_i^2(x_{\min} - x_{\max})(c_i - x_{\max})\}^{1/2} \end{array}\right] \times$$
$$[4w_i(x_{\max} - x_{\min})], \quad i = 1, 2, \ldots, n.$$

(3.14)

Based on total utility value U_T fuzzy numbers can be ranked. The fuzzy number corresponding to maximum utility value is ranked 'First' and others are ranked accordingly in descending order of utility magnitude. Higher the value of utility, the better is the performance; so corresponding ranking position would be high.

3.1.1.6 Procedural Framework

Agility evaluation has been made by the procedural framework as described by (Vinodh et al., 2011); with some modifications. This has been implemented in an empirical study. Results obtained thereof, have been analyzed, interpreted from managerial viewpoint and reported stepwise as follows.

1) Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of agile attributes

The linguistic terms have been used to assess the performance ratings (fuzzy appropriateness) and priority weights of agile criteria as well as various agile attributes since it is difficult for the decision-makers to determine the numeric score against a subjective attribute. The linguistic scale used by (Wei and Chen, 2009) has been adopted in this study.

In order to assess the performance rating of the agile attributes (in Grade-III) (Table 3.1), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Fair (F), Medium Good (MG), Good (G), Very Good (VG), Absolutely Good (AG)***} have been used.

In order to assess the importance weights (priority degree) of the agile attributes, the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized. The linguistic variables have been assumed accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes, supply network and competitive situation (Table 3.2).

2) Measurement of performance ratings and importance weights of agile attributes using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of agile attributes has been accepted by the decision-makers (DMs), the decision-making team has been advised to utilize aforesaid linguistic scales to assess performance rating as well as to assign importance weights according to their perception (Appendix: Table 3.3 and Tables 3.4-3.6).

3) Approximation of the linguistic terms by generalized trapezoidal fuzzy numbers

Using the concept of generalized trapezoidal fuzzy numbers set theory, the linguistic variables have been be approximated and the aggregated decision-making cum evaluation matrix has been constructed (Appendix: Tables 3.7-3.9). Aggregated fuzzy rating as well as aggregated priority weights have been determined based on the pooled opinion (average) provided by the decision-makers.

4) Determination of FAI

FAI represents the fuzzy agility index (Lin et al., 2006). The fuzzy index has been calculated at the criterion level and then extended to enabler level. Fuzzy index at Grade III (refer Table 3.1) encompasses several agile criterions. The fuzzy index of Grade-II agile attribute has been calculated using the formula:

$$U_{ij} = \frac{\sum_{k=1}^{n} \left(w_{ijk} \otimes U_{ijk}\right)}{\sum_{k=1}^{n} w_{ijk}} \tag{3.15}$$

Here U_{ijk} represent performance rating and w_{ijk} represent fuzzy weight for priority importance corresponding to agile criteria C_{ijk}, which is under C_{ij} agile attribute. C_{ij} is under the agile enabler C_i. $k = 1, 2, 3, ...n.$

The fuzzy index of Grade-I agile capability has been calculated as follows:

$$U_{i} = \frac{\sum_{j=1}^{n} \left(w_{ij} \otimes U_{ij}\right)}{\sum_{j=1}^{n} w_{ij}} \tag{3.16}$$

Here U_{ij} represent performance measure and w_{ij} represent fuzzy weight for priority importance corresponding to agile attribute C_{ij}. $j = 1, 2, 3, ...n.$

Thus, overall fuzzy index $U(FAI)$ has been calculated as follows:

$$U(FAI) = \frac{\sum_{i=1}^{n} \left(w_{i} \otimes U_{i}\right)}{\sum_{i=1}^{n} w_{i}} \tag{3.17}$$

Here U_i =Rating of i^{th} agile capability C_i; w_i =Weight of i^{th} agile capability, and $i = 1, 2, 3, ...n$.

For this case study, using (Appendix: Tables 3.7-3.9) the value of FAI becomes = **[0.75, 0.79, 0.89, 0.93; 1.0]** (Computation shown below).

$$U = {\left(U_1 \otimes w_1 \oplus U_2 \otimes w_2 \oplus U_3 \otimes w_3\right)}\Big/{\left(w_1 \oplus w_2 \oplus w_3\right)}$$

$$= \frac{\{(0.73,0.79,0.91,0.95;1.0) \oplus (0.49,0.57,0.75,0.82;1.0) \oplus (0.61,0.69,0.84,0.90;1.0)\}}{\{(0.95,0.98,1.00,1.00;1.0) \oplus (0.62,0.68,0.84,0.89;1.0) \oplus (0.86,0.91,0.97,0.99;1.0)\}}$$
$$= \frac{(1.83,2.05,2.50,2.67;1.0)}{(2.43,2.57,2.81,2.88;1.0)}$$
$$= (0.75,0.79,0.89,0.93;1.0)$$

5) Identification and analysis of obstacles for improvement

Computed score of FAI may be matched with an appropriate agility level decided by the top management based on a predefined agility scale (extent of agility scale). After evaluating FAI and the existing supply chain's agility level extent, simultaneously it is also felt indeed necessary to identify and analyze the obstacles (called agile barriers) for agility improvement. Therefore, the fuzzy agility appraisement system discussed above has been extended (Lin et al., 2006a, b; Vinodh and Devadarsan, 2011) to investigate on the weaker areas for improvement. In the present study the concept of comparison between two generalized trapezoidal fuzzy numbers (discussed in Section 3.1.1.5) has been utilized in order to compare various agile capabilities, and attributes according to their degree of performance (Table 3.10 and 3.11). Similarly, agile criterions (Grade III) can also be ranked. Because of large set of agile criterions, this comparison technique becomes cumbersome to the decision-makers and invites knowledge of computer programming to avoid adequate timing and confusion arising from manual comparison. Moreover, this technique is unable to provide any numeric ranking score. Therefore, the study explores the theory of computing utility value of fuzzy numbers by using maximizing as well as minimizing set. Based on the utility value of '*Fuzzy Performance Importance Index*' (to be described in later stage) corresponding to individual agile criteria in Grade III; the appropriate ranking order has been determined (Table 3.12). By this procedure poorly performing areas have been identified as well.

Performance ranking order is shown as follows (in descending order)

$$C_{321} \succ C_{31} \succ C_{213} \succ C_{111} \succ C_{122} \succ C_{131} \succ (C_{112} \approx C_{323}) \succ C_{211} \succ C_{212} \succ C_{222} \succ (C_{23} \approx C_{324})$$
$$\succ C_{113} \succ (C_{121} \approx C_{123}) \succ C_{221} \succ C_{322} \succ C_{132} \succ C_{33}$$

Apparently, it seems easy to rank various agile criterions (Grade III), agile attributes (Grade II) and agile capabilities (Grade I) in accordance with individual aggregated weighted fuzzy performance rating. In this approach, one may commit mistake towards estimating appropriate ranking position of an agile criteria/attribute which is of high priority weight but possessing very poor performance rating. In order to avoid this risk and uncertainty; it has been recommended that agile criterions (at Grade III) (C_{ijk}) may be ranked based on the value $U_{ijk} \otimes [(1,1,1,1;1)\Theta w_{ijk}]$ instead of using $U_{ijk} \otimes w_{ijk}$ straightforward. The term $U_{ijk} \otimes [(1,1,1,1;1)\Theta w_{ijk}]$ has been denoted as the *Fuzzy Performance Importance Index (FPII)*. The higher the FPII of a factor, the higher is the contribution. Similarly, agile attributes (at Grade II) (C_{ij}) are to be ranked based on the value $U_{ij} \otimes [(1,1,1,1;1)\Theta w_{ij}]$. Agile capabilities (at Grade I) (C_i) can also be ranked based on the value $U_i \otimes [(1,1,1,1;1)\Theta w_i]$. Here the symbol Θ represents '*minus*' operator.

The FPII has been calculated as follows, at Grade III

$$FPII_{ijk} = w'_{ijk} \otimes U_{ijk} \tag{3.18}$$

Here, $w'_{ijk} = [(1,1,1,1;1)\Theta w_{ijk}]$ (3.19)

w_{ijk} is the fuzzy importance weight of the agile criterion C_{ijk}.

FPII need to be ranked based on utility value U_T to identify individual criterion performance level. In doing so, poorly performing criterion can be identified (called agile barriers) and in future, attention must be paid to improve those criteria aspects in order to boost up agility degree.

The supply chains should be improved on the weak areas in order to achieve desired level of agility. To achieve this, from management practitioners, employees, workers should motivate themselves; should reconsider the causes of various loopholes, should review and rectify the existing purchase policy, supplier management, material handling, inventory policy, work environment, floor shop management, R&D, process technical aspects etc. towards achieving satisfactory level of agility.

3.1.1.7 Concluding Remarks

Managerial decision-making process often experience uncertain-vague data which is really difficult to analyze. Fuzzy logic has the capability to overcome such imprecise linguistic human judgment. Supply chain agility, as a whole, is a conceptual philosophy difficult to structure and estimate an overall agility index mathematically. In this part of study, an effort has been made to establish a scientific mathematical background to quantify overall agility degree and to assess the extent of successful performance of the key elements that stimulate agility. The fuzzy based agility evaluation model presented here can be effectively implemented in industries supply chain to attain competitive advantage in the marketplace. The advantages of the proposed model have been summarized as follows:

1. Quantitative estimation of overall agility degree.
2. Identification of agile barriers.
3. Benchmarking of various agile enterprises based on Fuzzy Agility Index (FAI).

Thus, proposed fuzzy based agility appraisement module aims to capture decision-makers' subjective information in a logical manner to finally compute overall agility degree. If number of decision-maker is very large, manual computation of overall agility index is cumbersome. To get rid of this, software may be developed in which decision-makers can provide their information online and finally, overall agility index may appear as output of the program.

Table 3.1: Agility appraisement framework for integrated supply chain

Goal	Agile Capabilities/Providers (Grade I) (U_i)	Agile Attributes (Grade II) (U_{ij})	Agile Criteria (Grade III) (U_{ijk})
Supply Chain Agility (U)	Flexibility (U_1)	Sourcing Flexibility (U_{11})	Numerous available suppliers (U_{111})
			Flexibility in volume (U_{112})
			Flexibility in variety (U_{113})
		Manufacturing Flexibility (U_{12})	Flexible manufacturing system (U_{121})
			CAM based manufacturing (U_{122})
			Variety and volume of productions (U_{123})
		Delivery Flexibility (U_{13})	Variety of supply schedules for meeting customers' needs (U_{131})
			Flexibility in volume of product (U_{132})
	Responsiveness (U_2)	Sourcing Responsiveness (U_{21})	Adaptability of deliver time by suppliers (U_{211})
			Suppliers' delivery time (U_{212})
			Supplier relation management (U_{213})
		Manufacturing Responsiveness (U_{22})	Time of establishment and changing parts (U_{221})
			Responsiveness level to the market changes (U_{222})
		Delivery Responsiveness (U_{23})	Delivery Responsiveness (U_{23})
	Competency (U_3)	Cooperation and internal-external balance (U_{31})	Cooperation and internal-external balance (U_{31})
		Manufacturing competency (U_{32})	New product introduce (U_{321})
			Quality of products or services (U_{322})
			Integration (U_{323})
			Time of new product development (U_{324})
		Capabilities of human resources (U_{33})	Capabilities of human resources (U_{33})

Table 3.2: Definitions of linguistic variables for criteria ratings and weights
(A-9 member linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	(0, 0, 0, 0; 1.0)
Very Poor (VP)	Very Low (VL)	(0, 0, 0.02, 0.07; 1.0)
Poor (P)	Low (L)	(0.04, 0.1, 0.18, 0.23; 1.0)
Medium Poor (MP)	Medium Low (ML)	(0.17, 0.22, 0.36, 0.42; 1.0)
Medium (M)	Medium (M)	(0.32, 0.41, 0.58, 0.65; 1.0)
Medium Good (MG)	Medium High (MH)	(0.58, 0.63, 0.80, 0.86; 1.0)
Good (G)	High (H)	(0.72, 0.78, 0.92, 0.97; 1.0)
Very Good (VG)	Very High (VH)	(0.93, 0.98, 1.0, 1.0; 1.0)
Absolutely Good (AG)	Absolutely High (AH)	(1.0, 1.0, 1.0, 1.0; 1.0)

Table 3.10: Ranking order of agile capabilities at Grade I by comparing corresponding $(FPII)$

C_i	$w'_i = [(1,1,1,1;1) - w_i]$	$(FPII)_i$	$\Re$	Mode	Divergence	Left Spread	Right Spread	Performance Ranking Order
C_1	(0.00,0.00,0.02,0.05; 1)	(0.00,0.00,0.02,0.05; 1)	0.0175	0.010	0.050	0.00	0.03	$C_1 \prec C_3 \prec C_2$
C_2	(0.11,0.16,0.32,0.38; 1)	(0.09,0.14,0.29,0.35; 1)	0.2175	0.215	0.260	0.05	0.06	
C_3	(0.01,0.03,0.09,0.14; 1)	(0.01,0.02,0.08,0.13; 1)	0.060	0.050	0.120	0.01	0.05	

Table 3.11: Ranking order of agile attributes at Grade II *(under each agile capability)* by comparing corresponding $(FPII)$

C_i	C_{ij}	$w'_{ij} = [(1,1,1,1;1) - w_{ij}]$	$(FPII)_{ij}$	$\Re$	Mode	Divergence	Left Spread	Right Spread	Performance Ranking Order
C_1	C_{11}	(0.02,0.06,0.16,0.21; 1)	(0.02,0.05,0.15,0.20; 1)	0.105	0.100	0.180	0.030	0.050	$C_{13} \prec C_{11} \prec C_{12}$
	C_{12}	(0.18,0.24,0.40,0.46; 1)	(0.11,0.16,0.34,0.41; 1)	0.255	0.250	0.300	0.050	0.070	
	C_{13}	(0.00,0.00,0.01,0.03; 1)	(0.00,0.00,0.01,0.03; 1)	0.010	0.005	0.030	0.000	0.020	
C_2	C_{21}	(0.00,0.00,0.02,0.05; 1)	(0.00,0.00,0.02,0.05; 1)	0.0175	0.010	0.050	0.00	0.03	$C_{21} \prec C_{23} \prec C_{22}$
	C_{22}	(0.28,0.35,0.52,0.60; 1)	(0.12,0.18,0.35,0.45; 1)	0.2750	0.265	0.330	0.06	0.10	
	C_{23}	(0.01,0.03,0.09,0.14; 1)	(0.01,0.03,0.09,0.14; 1)	0.0675	0.060	0.130	0.02	0.05	
C_3	C_{31}	(0.14,0.20,0.37,0.42; 1)	(0.13,0.20,0.37,0.42; 1)	0.2800	0.285	0.290	0.07	0.05	$C_{33} \prec C_{32} \prec C_{31}$
	C_{32}	(0.02,0.06,0.16,0.21; 1)	(0.02,0.05,0.15,0.20; 1)	0.1050	0.100	0.180	0.03	0.05	
	C_{33}	(0.00,0.00,0.01,0.03; 1)	(0.00,0.00,0.01,0.02; 1)	0.0075	0.005	0.020	0.00	0.01	

Table 3.12: Ranking order of agile criterions at Grade III by computing corresponding utility score

C_{ijk}	$w'_{ijk} = [(1,1,1,1;1) - w_{ijk}]$	$(FPII)_{ijk}$	$U_T\ (k=1)$	Rank
C_{111}	(0.17,0.21,0.33,0.39; 1)	(0.13,0.17,0.31,0.38; 1)	0.4432	***4***
C_{112}	(0.03,0.08,0.22,0.28; 1)	(0.02,0.07,0.21,0.27; 1)	0.2751	***7***
C_{113}	(0.01,0.03,0.09,0.14; 1)	(0.01,0.02,0.08,0.14; 1)	0.1304	***12***
C_{121}	(0.01,0.03,0.09,0.14; 1)	(0.01,0.02,0.07,0.12; 1)	0.1159	***13***
C_{122}	(0.11,0.16,0.32,0.38; 1)	(0.07,0.11,0.28,0.35; 1)	0.3694	***5***
C_{123}	(0.01,0.03,0.09,0.14; 1)	(0.01,0.02,0.07,0.12; 1)	0.1159	***13***
C_{131}	(0.07,0.12,0.27,0.33; 1)	(0.06,0.11,0.26,0.32; 1)	0.3482	***6***
C_{132}	(0.00,0.00,0.02,0.07; 1)	(0.00,0.00,0.02,0.06; 1)	0.0500	***16***
C_{211}	(0.03,0.08,0.22,0.28; 1)	(0.02,0.07,0.20,0.27; 1)	0.2716	***8***
C_{212}	(0.02,0.06,0.16,0.21; 1)	(0.02,0.05,0.15,0.21; 1)	0.2117	***9***
C_{213}	(0.14,0.20,0.37,0.42; 1)	(0.12,0.18,0.36,0.41; 1)	0.4812	***3***
C_{221}	(0.01,0.03,0.09,0.14; 1)	(0.00,0.01,0.05,0.09; 1)	0.0837	***14***
C_{222}	(0.02,0.06,0.16,0.21; 1)	(0.01,0.04,0.13,0.18; 1)	0.1814	***10***
C_{23}	(0.01,0.03,0.09,0.14; 1)	(0.01,0.03,0.09,0.14; 1)	0.1406	***11***
C_{31}	(0.14,0.20,0.37,0.42; 1)	(0.13,0.20,0.37,0.42; 1)	0.5030	***2***
C_{321}	(0.28,0.35,0.52,0.60; 1)	(0.21,0.27,0.47,0.56; 1)	0.6485	***1***
C_{322}	(0.00,0.00,0.02,0.07; 1)	(0.00,0.00,0.02,0.07; 1)	0.0573	***15***
C_{323}	(0.03,0.08,0.22,0.28; 1)	(0.02,0.07,0.21,0.27; 1)	0.2751	***7***
C_{324}	(0.01,0.03,0.09,0.14; 1)	(0.01,0.03,0.09,0.14; 1)	0.1406	***11***
C_{33}	(0.00,0.00,0.01,0.03; 1)	(0.00,0.00,0.01,0.02; 1)	0.0175	***17***

3.1.2 Agility Appraisement using GIVFNs Set

3.1.2.1 Overview

Supply chain agility is the ability of the supply chain partner organizations to adapt quickly with the rapid changes in business environments. It requires an appropriate blending of coordination, communication and speed in procurement, inventory, assembly and delivery of products and services, as well as the return and re-use of materials and services. Supply chain agility also encompasses related human, financial and information capital flows across organizations that facilitate effective and efficient fulfillment of orders. Successful agile supply chains depend on a number of managerial issues such as organizational resistance to change, inter-functional conflicts, joint production planning, profit sharing, team oriented performance measures, shifts in channel power, information sharing, real time communication, and technical compatibility. Such issues are relevant to both manufacturing and service sectors. The objective of this part of work is to contribute important insights to the methodology of performance appraisement of agile supply chain. An approach based on Interval-Valued Fuzzy Set (IVFS) has been adopted for agility appraisal in supply chain. IVFS theory (Moore, 1966; Grattan-Guinness, 1975; Gorzalczany, 1987; Wang and li, 1998; Karnik and Mendel, 2001; Grzegorzewski, 2004; Cornelis et al., 2006) has been efficiently explored in order to order to assess the contributions of various agility capabilities in an ambiguous fuzzy environment.

3.1.2.2 Supply Chain Agility: Traditional versus Agile Supply Chain

The difference between supply chain management and supply chain agility is the extent of capability that the organization possesses. Key to the success of an agile supply chain is the speed and flexibility with which these activities can be accomplished effectively and the realization that customer needs and customer satisfaction are the main stimulants for the network. Customer satisfaction is paramount. Achieving this capability requires all physical and logical events within the supply chain to be enacted swiftly, accurately, and effectively. The faster parts, information, and decisions flow through an organization, the faster it can respond to customer needs.

Agile organizations are basically market-driven, with more product research and short development and introduction cycles. The focus is on quickly satisfying the issues involved in supply chain, the chain of events from a customer's order inquiry through complete satisfaction of that consumer. All physical events are enacted quickly and accurately. The faster materials, information, and decisions flow through an organization the faster it can respond to the demands of the market. The keys are flow and time.

Achieving agility starts with the physical flow of parts, from the point of supply, through the factory, and shipment through agile distribution channels. It emphasizes closing the distance between each point in the flow. Within the factory successive operations in the work chain are physically coupled, removing non-value-adding functions and inducing velocity. Parts move with high velocity through the work chain. Natural points of delay are eliminated and simplified.

The information chain is streamlined and electronically linked at every point, so that information flow is direct without interruptions and delays. Business cycle times are to be reduced to the time it actually takes to effectively process information.

Agility requires a company to be nimble in its response to changing needs of the market. Time-to-market is short. Service is highly responsive and open to new challenges. Quality is impeccable. The factory is able to quickly changeover from one product type to the next. Flexible manufacturing and assembly cells provide this physical capability. Quick changeover techniques are mastered using modular fixturing. Tools are located in close proximity to the point of usage. Equipment is collocated for speed and responsiveness.

An agile company is organized for velocity and flexibility by reducing the number of vertical and horizontal layers in the organization chart and rearranging them around natural processes. Organizational functions are collocated into physical groups that work fast. Physical walls that stand in the way of good communication are removed.

Supply Chain Agility is in direct opposition with traditional manufacturing approaches characterized by use of economic order quantities, high capacity utilization, and high inventory. It requires radical change. Excess capacity is welcome instead of taboo. Make-to-order capability replaces mass production, and lot sizes of one replace EOQ's.

A major issue with supply chain agility is the high capitalization often required for flexibility in the production and assembly areas. However, just like anything else, supply chain agility is no panacea, nor should it be embraced as a religion. It is an operational strategy that, if implemented properly, would provide a new dimension to competing: quickly introducing new customized high quality products and delivering them with unprecedented lead times, swift decisions, and manufacturing products with high velocity.

3.1.2.3 Problem Statement

Detailed literature review on supply chain agility assessment has already been provided in Section 3.1.1.2. As a continuation of the previous work reported in Section 3.1.1, the application feasibility of GIVFNs set theory has been attempted here for supply chain agility appraisement. Apart from estimating overall agility index, the study has been extended to identify ill-performing areas of the supply chain (agile barriers). This can be achieved through performance ranking of various agile criterions. As the said agility appraisement module is based on fuzzy concept; determination of ranking order for different agile criterions requires exploration of the theory of fuzzy numbers ranking. Generalized fuzzy numbers can easily be ranked based on their overall utility value obtained on applying the theory of 'maximizing set and minimizing set'. As this study utilizes IVFNs, performance ranking of agile criterion seems difficult. This is because; the theory on ranking of interval-valued trapezoidal fuzzy number is not readily available in literature. So we have to think of adapting alternative means. There exists need for further research towards addressing ranking, similarity measure and comparison aspects between two interval-valued trapezoidal fuzzy numbers to be appropriately fitted in the decision-making process.

Motivated by this concept, the present study aims to develop a group decision-making procedural hierarchy based on generalized interval-valued trapezoidal fuzzy number sets for agility index appraisement in supply chain. Detailed methodology of the proposed approach has been illustrated through an empirical study. The appraisement hierarchy utilized in Sec 3.1.1 (shown in Table 3.1) has also been adapted in the present case.

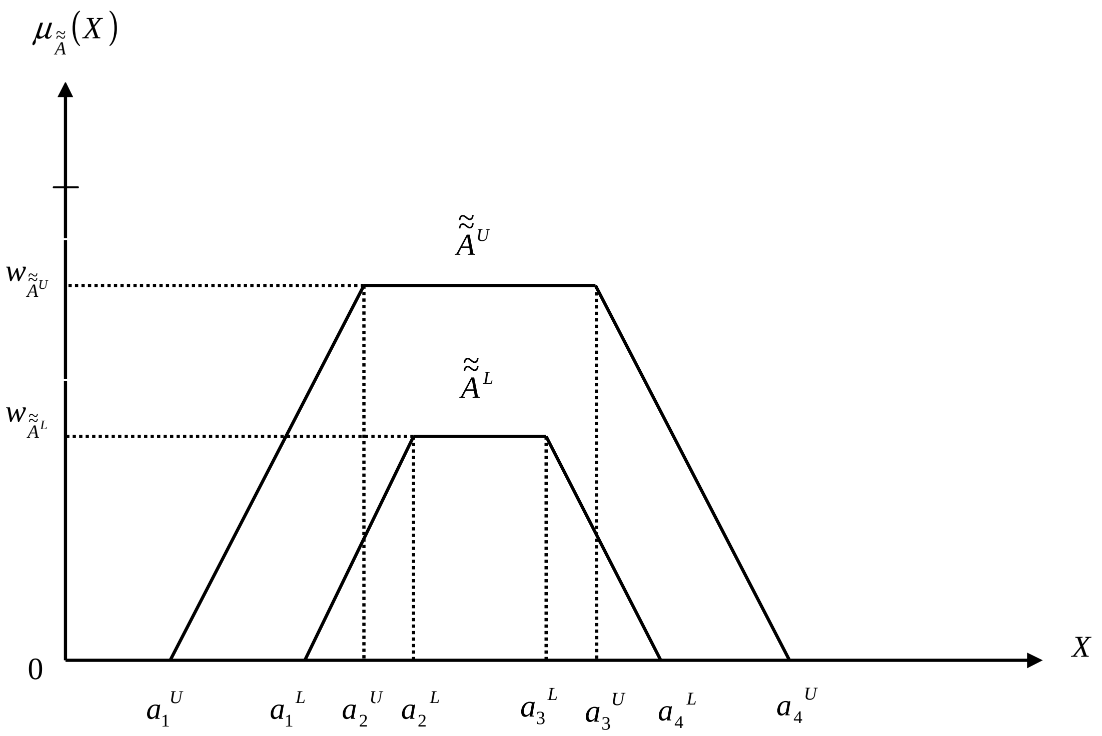

Fig. 3.2: Interval-valued trapezoidal fuzzy numbers (Liu and Wang; 2011)

3.1.2.4 Introduction to Interval-Valued Trapezoidal Fuzzy Numbers (Wei and Chen, 2009)

Wang and Li (2001) represented the interval-valued trapezoidal fuzzy numbers as follows (Fig. 3.2):

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$$

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,$$

Here, $0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1$, and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$.

$$0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U}$$

From Fig. 3.2, it can be concluded that interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}$ consists of the lower values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper values of interval-valued trapezoidal fuzzy number $\tilde{\tilde{A}}^U$.

3.1.2.5 The Operation Rules of IV-Trapezoidal Fuzzy Numbers (Wei and Chen, 2009)

Suppose that,

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$ and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$ are the two interval-valued trapezoidal fuzzy numbers, where,

$$\begin{aligned}
&0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1,\\
&0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,\\
&0 \le w_{\tilde{\tilde{A}}^L} \le w_{\tilde{\tilde{A}}^U} \le 1, \quad \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U\\
&0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1,\\
&0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1,\\
&0 \le w_{\tilde{\tilde{B}}^L} \le w_{\tilde{\tilde{B}}^U} \le 1, \quad \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U
\end{aligned}$$

1. The sum of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} \oplus \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \oplus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right]$$

(3.20)

2. The difference of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} - \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} - \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] - \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L - b_4^L, a_2^L - b_3^L, a_3^L - b_2^L, a_4^L - b_1^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U - b_4^U, a_2^U - b_3^U, a_3^U - b_2^U, a_4^U - b_1^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right]$$

(3.21)

3. The product of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}} \otimes \tilde{\tilde{B}}$:

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right] \otimes \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$$

$$= \left[\left(a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)\right), \left(a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)\right)\right]$$

(3.22)

3.1.2.6 The Distance between Two IV-Trapezoidal Fuzzy Numbers

Suppose that,

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}^L}\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}^U}\right)\right]$ and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}^L}\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}^U}\right)\right]$ are the two generalized interval-valued trapezoidal fuzzy numbers, then the distance of two interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ is calculated as follows:

a. Utilize the formula (15) to calculate the coordinate of COG points $\left(x_{\tilde{\tilde{A}}^L}, y_{\tilde{\tilde{A}}^L}\right), \left(x_{\tilde{\tilde{A}}^U}, y_{\tilde{\tilde{A}}^U}\right), \left(x_{\tilde{\tilde{B}}^L}, y_{\tilde{\tilde{B}}^L}\right), \left(x_{\tilde{\tilde{B}}^U}, y_{\tilde{\tilde{B}}^U}\right)$ which belong to the generalized interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U, \tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U$.

b. The distance of two interval-valued trapezoidal fuzzy number is:

$$d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{2}\sqrt{\left\{\left(y_{\tilde{\tilde{A}}^L} - y_{\tilde{\tilde{B}}^L}\right)^2 + \left(x_{\tilde{\tilde{A}}^L} - x_{\tilde{\tilde{B}}^L}\right)^2 + \left(y_{\tilde{\tilde{A}}^U} - y_{\tilde{\tilde{B}}^U}\right)^2 + \left(x_{\tilde{\tilde{A}}^U} - x_{\tilde{\tilde{B}}^U}\right)^2\right\}} \quad (3.23)$$

Here, $d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$ satisfies the following properties:

(i) If $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ are normalized interval-valued trapezoidal fuzzy numbers, then $0 \le d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) \le 1$.

(ii) $\tilde{\tilde{A}} = \tilde{\tilde{B}} \Rightarrow d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 0$

(iii) $d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = d\left(\tilde{\tilde{B}}, \tilde{\tilde{A}}\right)$

(iv) $d\left(\tilde{\tilde{A}}, \tilde{\tilde{C}}\right) + d\left(\tilde{\tilde{C}}, \tilde{\tilde{B}}\right) \ge d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$

In the real life decision making, it is difficult to get the form of generalized interval-valued trapezoidal fuzzy numbers for the attribute values and weights directly by the decision-makers. So, the form of linguistic terms is usually adopted. Wei and Chen (2009) utilized the interval-valued trapezoidal fuzzy numbers to represent the 9-member linguistic terms (Table 3.13), which has also been used in the present work.

3.1.2.7 Degree of Similarity Measurement between Two IV-Fuzzy Numbers

Combining the concepts of geometric distance, the perimeter, the height and the COG points, the degree of similarity between interval-valued trapezoidal fuzzy numbers can be calculated (Wei and Chen, 2009; Chen and Sanguansat, 2011). Assuming that there are two interval-valued trapezoidal fuzzy numbers:

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; \hat{w}_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; \hat{w}_{\tilde{\tilde{A}}}^U\right)\right]$ and

$$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; \hat{w}_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; \hat{w}_{\tilde{\tilde{B}}}^U\right)\right]$$

Here, $0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1, \quad 0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1,$

$$0 \le \hat{w}_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1,\ \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U.$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1, \quad 0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1,$$

$$0 \le \hat{w}_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1,\ \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U.$$

The procedural steps for calculating the degree of similarity between interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ are summarized below (Wei and Chen, 2009).

Step 1: Calculate the areas $A\left(\tilde{\tilde{A}}^L\right)$ and $A\left(\tilde{\tilde{A}}^U\right)$ of the lower trapezoidal fuzzy number $\tilde{\tilde{A}}^L$ and the upper trapezoidal fuzzy number $\tilde{\tilde{A}}^U$, respectively, shown as follows:

$$A\left(\tilde{\tilde{A}}^L\right)=\frac{\left(a_4^L+a_3^L-a_2^L-a_1^L\right)\times\hat{w}_{\tilde{\tilde{A}}^L}}{2}, \tag{3.24}$$

$$A\left(\tilde{\tilde{A}}^U\right)=\frac{\left(a_4^U+a_3^U-a_2^U-a_1^U\right)\times\hat{w}_{\tilde{\tilde{A}}^U}}{2}. \tag{3.25}$$

In the same way, calculate the areas $A\left(\tilde{\tilde{B}}^L\right)$ and $A\left(\tilde{\tilde{B}}^U\right)$ of the lower trapezoidal fuzzy number $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy number $\tilde{\tilde{B}}^U$, respectively, shown as follows:

$$A\left(\tilde{\tilde{B}}^L\right)=\frac{\left(b_4^L+b_3^L-b_2^L-b_1^L\right)\times\hat{w}_{\tilde{\tilde{B}}^L}}{2}, \tag{3.26}$$

$$A\left(\tilde{\tilde{B}}^U\right)=\frac{\left(b_4^U+b_3^U-b_2^U-b_1^U\right)\times\hat{w}_{\tilde{\tilde{B}}^U}}{2}. \tag{3.27}$$

Step 2: Calculate the COG points $\left(x^*_{\tilde{\tilde{A}}^L}, y^*_{\tilde{\tilde{A}}^L}\right),\left(x^*_{\tilde{\tilde{A}}^U}, y^*_{\tilde{\tilde{A}}^U}\right),\left(x^*_{\tilde{\tilde{B}}^L}, y^*_{\tilde{\tilde{B}}^L}\right),\left(x^*_{\tilde{\tilde{B}}^U}, y^*_{\tilde{\tilde{B}}^U}\right)$ of $\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U$, respectively, by the following equations.

$$x^*_{\tilde{\tilde{A}}^L}=\frac{y^*_{\tilde{\tilde{A}}^L}\left(a_3^L+a_2^L\right)+\left(a_4^L+a_1^L\right)\left(\hat{w}_{\tilde{\tilde{A}}^L}-y^*_{\tilde{\tilde{A}}^L}\right)}{2\hat{w}_{\tilde{\tilde{A}}^L}} \tag{3.28}$$

$$y^*_{\tilde{\tilde{A}}^L}=\begin{cases}\dfrac{\hat{w}_{\tilde{\tilde{A}}^L}\left(\dfrac{a_3^L-a_2^L}{a_4^L-a_1^L}+2\right)}{6}, & if\ \ a_1^L\neq a_4^L\ \ and\ 0<\hat{w}_{\tilde{\tilde{A}}^L}\leq 1,\\ \dfrac{\hat{w}_{\tilde{\tilde{A}}^L}}{2}, & if\ \ a_1^L=a_4^L\ \ and\ 0<\hat{w}_{\tilde{\tilde{A}}^L}\leq 1.\end{cases} \tag{3.29}$$

$$x^*_{\tilde{\tilde{A}}^U}=\frac{y^*_{\tilde{\tilde{A}}^U}\left(a_3^U+a_2^U\right)+\left(a_4^U+a_1^U\right)\left(\hat{w}_{\tilde{\tilde{A}}^U}-y^*_{\tilde{\tilde{A}}^U}\right)}{2\hat{w}_{\tilde{\tilde{A}}^U}} \tag{3.30}$$

$$y^*_{\tilde{\tilde{A}}^U}=\begin{cases}\dfrac{\hat{w}_{\tilde{\tilde{A}}^U}\left(\dfrac{a_3^U-a_2^U}{a_4^U-a_1^U}+2\right)}{6}, & if\ \ a_1^U\neq a_4^U\ \ and\ 0<\hat{w}_{\tilde{\tilde{A}}^U}\leq 1,\\ \dfrac{\hat{w}_{\tilde{\tilde{A}}^U}}{2}, & if\ \ a_1^U=a_4^U\ \ and\ 0<\hat{w}_{\tilde{\tilde{A}}^U}\leq 1.\end{cases} \tag{3.31}$$

$$x^*_{\tilde{\tilde{B}}^L} = \frac{y^*_{\tilde{\tilde{B}}^L}\left(b_3^L + b_2^L\right) + \left(b_4^L + b_1^L\right)\left(\hat{w}_{\tilde{\tilde{B}}^L} - y^*_{\tilde{\tilde{B}}^L}\right)}{2\hat{w}_{\tilde{\tilde{B}}^L}} \tag{3.32}$$

$$y^*_{\tilde{\tilde{B}}^L} = \begin{cases} \dfrac{\hat{w}_{\tilde{\tilde{B}}^L}\left(\dfrac{b_3^L - b_2^L}{b_4^L - b_1^L} + 2\right)}{6}, & if\ \ b_1^L \neq b_4^L\ \ and\ 0 < \hat{w}_{\tilde{\tilde{B}}^L} \leq 1, \\ \dfrac{\hat{w}_{\tilde{\tilde{B}}^L}}{2}, & if\ \ b_1^L = b_4^L\ \ and\ 0 < \hat{w}_{\tilde{\tilde{B}}^L} \leq 1. \end{cases} \tag{3.33}$$

$$x^*_{\tilde{\tilde{B}}^U} = \frac{y^*_{\tilde{\tilde{B}}^U}\left(b_3^U + b_2^U\right) + \left(b_4^U + b_1^U\right)\left(\hat{w}_{\tilde{\tilde{B}}^U} - y^*_{\tilde{\tilde{B}}^U}\right)}{2\hat{w}_{\tilde{\tilde{B}}^U}} \tag{3.34}$$

$$y^*_{\tilde{\tilde{B}}^U} = \begin{cases} \dfrac{\hat{w}_{\tilde{\tilde{B}}^U}\left(\dfrac{b_3^U - b_2^U}{b_4^U - b_1^U} + 2\right)}{6}, & if\ \ b_1^U \neq b_4^U\ \ and\ 0 < \hat{w}_{\tilde{\tilde{B}}^U} \leq 1, \\ \dfrac{\hat{w}_{\tilde{\tilde{B}}^U}}{2}, & if\ \ b_1^U = b_4^U\ \ and\ 0 < \hat{w}_{\tilde{\tilde{B}}^U} \leq 1. \end{cases} \tag{3.35}$$

<u>Step 3:</u> Calculate the COG point $\left(x^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{A}}}\right)$ of the interval-valued fuzzy number $\tilde{\tilde{A}}$, where

$$x^*_{\tilde{\tilde{A}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{A}}^U\right) \times x^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right) \times x^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)}, & if\ \ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.36}$$

$$y^*_{\tilde{\tilde{A}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{A}}^U\right) \times y^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right) \times y^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)}, & if\ \ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.37}$$

In the same way, calculate the COG point $\left(x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{B}}}\right)$ of the interval-valued fuzzy number $\tilde{\tilde{B}}$, where

$$x^*_{\tilde{\tilde{B}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{B}}^U\right) \times x^*_{\tilde{\tilde{B}}^U} - A\left(\tilde{\tilde{B}}^L\right) \times x^*_{\tilde{\tilde{B}}^L}}{A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right)}, & if\ \ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.38}$$

$$y^*_{\tilde{\tilde{B}}} = \begin{cases} \dfrac{A\left(\tilde{\tilde{B}}^U\right) \times y^*_{\tilde{\tilde{B}}^U} - A\left(\tilde{\tilde{B}}^L\right) \times y^*_{\tilde{\tilde{B}}^L}}{A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right)}, & if \ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases}$$ (3.39)

Step 4: Calculate the degree of similarity $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right)$ between the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$, shown as follows:

$$S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) = \begin{cases} \left[1 - \dfrac{\sum_{i=1}^{4} \left|a_i^L - b_i^L\right|}{4}\right] \times \dfrac{\min\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \min\left(\hat{w}_{\tilde{\tilde{A}}^L}, \hat{w}_{\tilde{\tilde{B}}^L}\right)}{\max\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \max\left(\hat{w}_{\tilde{\tilde{A}}^L}, \hat{w}_{\tilde{\tilde{B}}^L}\right)}, & if \ \min\left(\hat{w}_{\tilde{\tilde{A}}^L}, \hat{w}_{\tilde{\tilde{B}}^L}\right) \neq 0, \\ 0, & otherwise. \end{cases}$$ (3.40)

Here,

$$L\left(\tilde{\tilde{A}}^L\right) = \sqrt{\left(a_1^L - a_2^L\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^L}} + \sqrt{\left(a_3^L - a_4^L\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^L}} + \left(a_3^L - a_2^L\right) + \left(a_4^L - a_1^L\right), \quad (3.41)$$

$$L\left(\tilde{\tilde{B}}^L\right) = \sqrt{\left(b_1^L - b_2^L\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^L}} + \sqrt{\left(b_3^L - b_4^L\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^L}} + \left(b_3^L - b_2^L\right) + \left(b_4^L - b_1^L\right), \quad (3.42)$$

Also, $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) \in [0,1]$.

Calculate the degree of similarity $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)$ between the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^U$, shown as follows:

$$S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) = \begin{cases} \left[1 - \dfrac{\sum_{i=1}^{4} \left|a_i^U - b_i^U\right|}{4}\right] \times \dfrac{\min\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \min\left(\hat{w}_{\tilde{\tilde{A}}^U}, \hat{w}_{\tilde{\tilde{B}}^U}\right)}{\max\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \max\left(\hat{w}_{\tilde{\tilde{A}}^U}, \hat{w}_{\tilde{\tilde{B}}^U}\right)}, & if \ \min\left(\hat{w}_{\tilde{\tilde{A}}^U}, \hat{w}_{\tilde{\tilde{B}}^U}\right) \neq 0, \\ 0, & otherwise. \end{cases}$$ (3.43)

Here,

$$L\left(\tilde{\tilde{A}}^U\right) = \sqrt{\left(a_1^U - a_2^U\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^U}} + \sqrt{\left(a_3^U - a_4^U\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^U}} + \left(a_3^U - a_2^U\right) + \left(a_4^U - a_1^U\right), \quad (3.44)$$

$$L\left(\tilde{\tilde{B}}^U\right) = \sqrt{\left(b_1^U - b_2^U\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^U}} + \sqrt{\left(b_3^U - b_4^U\right)^2 + \hat{w}^2_{\tilde{\tilde{B}}^U}} + \left(b_3^U - b_2^U\right) + \left(b_4^U - b_1^U\right), \quad (3.45)$$

Also, $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) \in [0,1]$.

Step 5: Calculate the difference Δx on the x- axis and the difference Δy on the y- axis of the COG points of the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ shown as follows:

$$\Delta x = \begin{cases} \left|x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}}\right|, & if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0\ \ and\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.46}$$

$$\Delta y = \begin{cases} \left|y^*_{\tilde{\tilde{A}}} - y^*_{\tilde{\tilde{B}}}\right|, & if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0\ \ and\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.47}$$

Step 6: Calculate the degree of similarity $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$ between the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ as follows:

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left[\frac{S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) + \left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)}{2} \times (1-\Delta x) \times (1-\Delta y)\right]^{\left(\frac{1}{1+2t}\right)} \times \left(1 - \left|\hat{w}^U_{\tilde{\tilde{A}}} - \hat{w}^U_{\tilde{\tilde{B}}} - \hat{w}^L_{\tilde{\tilde{A}}} + \hat{w}^L_{\tilde{\tilde{B}}}\right|\right)^{\frac{u}{2}}, \tag{3.48}$$

Here,

$$t = \begin{cases} 1, & if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0\ \ and\ \ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, & otherwise. \end{cases} \tag{3.49}$$

$$u = \begin{cases} 1, & if\ a_1^U = a_4^U\ \ and\ \ b_1^U = b_4^U, \\ 0, & otherwise. \end{cases} \tag{3.50}$$

Also, $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) \in [0,1]$. The larger the value of $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)$, the more the similarity between the interval-valued trapezoidal fuzzy numbers $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$.

The aforesaid concept of similarity measure between interval-valued trapezoidal fuzzy numbers has the following properties (Wei and Chen, 2009).

Property 1: *When* $\hat{w}^U_{\tilde{\tilde{A}}} \neq 0$, *and* $\hat{w}^U_{\tilde{\tilde{B}}} \neq 0$, *two interval-valued trapezoidal fuzzy numbers* $\tilde{\tilde{A}}$ *and* $\tilde{\tilde{B}}$ *are identical if and only if* $S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 1$.

Property 2: $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=S\left(\tilde{\tilde{B}},\tilde{\tilde{A}}\right)$

Property 3: *If* $\tilde{\tilde{A}}$ *and* $\tilde{\tilde{B}}$ *are real values between zero and one, where* $\tilde{\tilde{A}}=a$ *and* $\tilde{\tilde{B}}=b$, *then* $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1-|a-b|.$

3.1.2.8 Division Operator ∅ for Interval-Valued Trapezoidal Fuzzy Numbers

Wei and Chen, (2009) proposed a new division operator for interval-valued trapezoidal fuzzy numbers for fuzzy risk analysis. According to them, given for two fuzzy numbers:

Let

$$\tilde{\tilde{A}}=\left[\left(a_1^L,a_2^L,a_3^L,a_4^L;\hat{w}_{\tilde{\tilde{A}}}^L\right),\left(a_1^U,a_2^U,a_3^U,a_4^U;\hat{w}_{\tilde{\tilde{A}}}^U\right)\right],\ \tilde{\tilde{B}}=\left[\left(b_1^L,b_2^L,b_3^L,b_4^L;\hat{w}_{\tilde{\tilde{B}}}^L\right),\left(b_1^U,b_2^U,b_3^U,b_4^U;\hat{w}_{\tilde{\tilde{B}}}^U\right)\right],$$

$$U^L=\left\{a_1^L/b_1^L,\ a_2^L/b_2^L,\ a_3^L/b_3^L,\ a_4^L/b_4^L\right\},\ U^U=\left\{a_1^U/b_1^U,\ a_2^U/b_2^U,\ a_3^U/b_3^U,\ a_4^U/b_4^U\right\},\tag{3.51}$$

$x^L=\min\left(U^L\right), x^U=\min\left(U^U\right), y^L=\max\left(U^L\right), y^U=\max\left(U^U\right)$, where

$$0\le a_1^L\le a_2^L\le a_3^L\le a_4^L\le 1,$$
$$0\le a_1^U\le a_2^U\le a_3^U\le a_4^U\le 1,$$
$$0\le b_1^L\le b_2^L\le b_3^L\le b_4^L\le 1,$$
$$0\le b_1^U\le b_2^U\le b_3^U\le b_4^U\le 1.$$

The division operator ∅ proposed by (Wei and Chen, 2009) between interval-valued trapezoidal fuzzy numbers has been presented follows:

$$\tilde{\tilde{A}}\varnothing\tilde{\tilde{B}}=\left[\left(a_1^L,a_2^L,a_3^L,a_4^L;\hat{w}_{\tilde{\tilde{A}}}^L\right),\left(a_1^U,a_2^U,a_3^U,a_4^U;\hat{w}_{\tilde{\tilde{A}}}^U\right)\right]\varnothing\left[\left(b_1^L,b_2^L,b_3^L,b_4^L;\hat{w}_{\tilde{\tilde{B}}}^L\right),\left(b_1^U,b_2^U,b_3^U,b_4^U;\hat{w}_{\tilde{\tilde{B}}}^U\right)\right]$$

$$=\begin{bmatrix}\left(\min\left(U^L\right),\min\left(U^L-x^L\right),\max\left(U^L-y^L\right),\max\left(U^L\right);\min\left(\hat{w}_{\tilde{\tilde{A}}}^L,\hat{w}_{\tilde{\tilde{B}}}^L\right)\right),\\ \left(\min\left(U^U\right),\min\left(U^U-x^U\right),\max\left(U^U-y^U\right),\max\left(U^U\right);\min\left(\hat{w}_{\tilde{\tilde{A}}}^U,\hat{w}_{\tilde{\tilde{B}}}^U\right)\right)\end{bmatrix}\tag{3.52}$$

Here $(U^L - x^L)$ denotes deleting the element x^L from the set U^L, $(U^U - x^U)$ denotes deleting the element x^U from the set U^U, $(U^L - y^L)$ denotes deleting the element y^L from the set U^L, $(U^U - y^U)$ denotes deleting the element y^U from the set U^U.

3.1.2.9 Proposed Framework: Managerial Implication

Agility evaluation has been made by the procedural framework as described as follows. This agility evaluation framework has been empirically studied, and the results obtained thereof, has been analyzed as well. The agility appraisal model adopted in the present study has already been furnished in Table 3.1, of Section 3.1.1.

1 Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of agile attributes

The linguistic terms have been used to assess performance ratings as well as priority weights of agile attributes; since it is difficult for the decision-makers to determine the score of a vague attribute. The linguistic scale used by (Wei and Chen, 2009) has been adopted in this study. In order to assess the performance rating of the agile criterions from Table 3.1 (in Grade-III), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used. In order to assess the importance weights (priority degree) of the agile capabilities/attributes as well as criterions, the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized. The linguistic variables have been assumed accepted among the selected group of DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation (Table 3.13).

2 Assignment of performance ratings and importance weights of various agile attribute using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of agile attributes has been accepted by the decision-makers (DMs), the decision-makers have been instructed to use aforesaid linguistic scales to assess the performance rating as well as to assign importance weights (Appendix: Table 3.14 and Tables 3.15-3.17).

3 Approximation of the linguistic terms by generalized interval-valued trapezoidal fuzzy numbers

Using the concept of generalized interval-valued trapezoidal fuzzy numbers set theory, the linguistic variables have been be approximated and the aggregated decision-making cum evaluation matrix (aggregated fuzzy weights and criteria ratings) has been constructed (Appendix: Tables 3.18-3.20).

4 Determination of FAI

FAI represents the overall enterprise level agility (Lin et al., 2006a, b). The fuzzy index has been calculated at the criterion level and then extended to enabler level. The fuzzy index of Grade-II agile attribute has been calculated using the formula:

$$U_{ij} = \frac{\sum_{k=1}^{n} \left(w_{ijk} \otimes U_{ijk} \right)}{\sum_{k=1}^{n} w_{ijk}} \tag{3.53}$$

Here U_{ijk} represent performance rating and w_{ijk} represent fuzzy weight for priority importance corresponding to agile criteria.

The fuzzy index of Grade-I agile capability has been calculated as follows:

$$U_{i} = \frac{\sum_{j=1}^{n} \left(w_{ij} \otimes U_{ij} \right)}{\sum_{j=1}^{n} w_{ij}} \tag{3.54}$$

Here U_{ij} represent performance measure and w_{ij} represent fuzzy weight for priority importance corresponding to agile attributes.

The overall fuzzy index has been calculated as follows:

$$U(FAI) = \frac{\sum_{i=1}^{n} \left(w_{i} \otimes U_{i} \right)}{\sum_{i=1}^{n} w_{i}} \tag{3.55}$$

Here U_i =Rating of i^{th} agile capabilities; w_i =Weight of i^{th} agile capabilities, and $i = 1, 2, 3, \ldots n$.

Now,

$$\sum_{i=1}^{n} U_i \otimes w_i = U_1 \otimes w_1 \oplus U_2 \otimes w_2 \oplus U_3 \otimes w_3$$

$$= \left\{ \begin{array}{l} [(0.78, 0.82, 0.91, 0.95; 0.8), (0.78, 0.82, 0.91, 0.95; 1.0)] \otimes [(0.96, 0.99, 1.00, 1.00; 0.8), (0.96, 0.99, 1.00, 1.00; 1.0)] \\ \oplus [(0.81, 0.85, 0.91, 0.95; 0.8), (0.81, 0.85, 0.91, 0.95; 1.0)] \otimes [(0.61, 0.67, 0.83, 0.89; 0.8), (0.61, 0.67, 0.83, 0.89; 1.0)] \\ \oplus [(0.68, 0.86, 0.86, 0.90; 0.8), (0.68, 0.86, 0.86, 0.90; 1.0)] \otimes [(0.88, 0.93, 0.98, 0.99; 0.8), (0.88, 0.93, 0.98, 0.99; 1.0)] \end{array} \right\}$$

$$= \left\{ \begin{array}{l} [(0.75, 0.81, 0.91, 0.95; 0.8), (0.75, 0.81, 0.91, 0.95; 1.0)] \oplus [(0.49, 0.57, 0.75, 0.83; 0.8), (0.49, 0.57, 0.75, 0.83; 1.0)] \\ \oplus [(0.60, 0.80, 0.84, 0.89; 0.8), (0.60, 0.80, 0.84, 0.89; 1.0)] \end{array} \right\}$$

$$= [(1.84, 2.18, 2.51, 2.67; 0.8), (1.84, 2.18, 2.51, 2.67; 1.0)]$$

And, $\sum_{i=1}^{n} w_i = (w_1 \oplus w_2 \oplus w_3) = [(2.45, 2.59, 2.81, 2.88; 0.8), (2.45, 2.59, 2.81, 2.88; 1.0)]$

Thus, $U(FAI) = \dfrac{[(1.84, 2.18, 2.51, 2.67; 0.8), (1.84, 2.18, 2.51, 2.67; 1.0)]}{[(2.45, 2.59, 2.81, 2.88; 0.8), (2.45, 2.59, 2.81, 2.88; 1.0)]}$

$$= [(0.75, 0.84, 0.89, 0.92; 0.8), (0.75, 0.84, 0.89, 0.92; 1.0)]$$

5 Identification and analysis of obstacles for improvement

Computed score of FAI may further be compared by matching with an appropriate agility level decided by the top management based on a predefined agility scale (extent of agility scale). The procedure of agility evaluation must not only stop with determination of agility level but also identify and analyze the obstacles for improvement (Vinodh et al., 2011). *Degree of similarity concept* has been proposed in this reporting in order to identify individual criterion performance level towards enhancing supply chain agility. It is obvious that individual agile criteria/ attributes contribute to the overall fuzzy agility index. The fuzzy number representing criteria rating for a particular criterion has been matched to the aggregated fuzzy agility measure at the preceding grade; the degree of similarity between two has been viewed as the degree of contribution of the said criterion upon corresponding fuzzy agility index at the preceding grade (Table 3.21). It has been assumed that larger the extent of similarity degree, the more is the contribution (or degree of satisfactory performance) corresponding to that particular criteria. Using this concept, poorly performing criterion have been sorted out (called agile barriers). In future, attention must be given to improve those criteria aspects in order to boost up supply chain agility degree. Sample calculation has been furnished below. The supply chain should focus on improvement of the weak areas in order to achieve expected agility level.

<u>Calculation for finding the Degree of similarity</u>

$$\tilde{\tilde{A}} = [(0.75,0.84,0.89,0.92;0.8),(0.75,0.84,0.89,0.92;1.0)],$$
$$\tilde{\tilde{B}} = [(0.84,0.88,0.96,0.98;0.8),(0.84,0.88,0.96,0.98;1.0)]$$

<u>Step 1:</u> Compute the areas $A\left(\tilde{\tilde{A}}^L\right)$, $A\left(\tilde{\tilde{A}}^U\right)$ and $A\left(\tilde{\tilde{B}}^L\right)$, $A\left(\tilde{\tilde{B}}^U\right)$

$$A\left(\tilde{\tilde{A}}^L\right) = \frac{\left(a_4^L + a_3^L - a_2^L - a_1^L\right)\times \hat{w}_{\tilde{\tilde{A}}^L}}{2},$$
$$= \frac{(0.92+0.89-0.84-0.75)\times 0.8}{2}$$
$$= 0.088$$
$$A\left(\tilde{\tilde{A}}^U\right) = \frac{\left(a_4^U + a_3^U - a_2^U - a_1^U\right)\times \hat{w}_{\tilde{\tilde{A}}^U}}{2}.$$
$$= \frac{(0.92+0.89-0.84-0.75)\times 1.0}{2}$$
$$= 0.11$$
$$A\left(\tilde{\tilde{B}}^L\right) = \frac{\left(b_4^L + b_3^L - b_2^L - b_1^L\right)\times \hat{w}_{\tilde{\tilde{B}}^L}}{2},$$
$$= \frac{(0.98+0.96-0.88-0.84)\times 0.8}{2}$$
$$= 0.088$$

$$A\left(\tilde{\tilde{B}}^U\right) = \frac{\left(b_4^U + b_3^U - b_2^U - b_1^U\right)\times \hat{w}_{\tilde{\tilde{B}}^U}}{2}.$$
$$= \frac{(0.98+0.96-0.88-0.84)\times 1}{2}$$
$$= 0.11$$

<u>Step 2</u>: Compute the COG points $\left(x^*_{\tilde{\tilde{A}}^L}, y^*_{\tilde{\tilde{A}}^L}\right), \left(x^*_{\tilde{\tilde{A}}^U}, y^*_{\tilde{\tilde{A}}^U}\right), \left(x^*_{\tilde{\tilde{B}}^L}, y^*_{\tilde{\tilde{B}}^L}\right), \left(x^*_{\tilde{\tilde{B}}^U}, y^*_{\tilde{\tilde{B}}^U}\right)$

$$y^*_{\tilde{\tilde{A}}^L} = \frac{\hat{w}_{\tilde{\tilde{A}}^L}\left(\dfrac{a_3^L - a_2^L}{a_4^L - a_1^L} + 2\right)}{6} = \frac{0.8\times 2.2941}{6} = 0.3059$$

$$x^*_{\tilde{\tilde{A}}^L} = \frac{y^*_{\tilde{\tilde{A}}^L}\left(a_3^L + a_2^L\right) + \left(a_4^L + a_1^L\right)\left(\hat{w}_{\tilde{\tilde{A}}^L} - y^*_{\tilde{\tilde{A}}^L}\right)}{2\hat{w}_{\tilde{\tilde{A}}^L}} = \frac{0.3059(0.89+0.84)+(0.92+0.75)(0.8-0.3059)}{2\times 0.8} = 0.8465$$

By using (Eqs. 3.28-3.35) following points can be calculated.

$$y^*_{\tilde{\tilde{A}}^U} = \frac{1\times 2.2941}{6} = 0.3823$$
$$x^*_{\tilde{\tilde{A}}^U} = \frac{0.3823\times 1.73 + 1.67\times(1-0.3823)}{2\times 1} = 0.84647$$
$$y^*_{\tilde{\tilde{B}}^L} = \frac{0.8\times 2.5714}{6} = 0.34285$$
$$x^*_{\tilde{\tilde{B}}^L} = \frac{0.34285(0.96+0.88)+(0.98+0.84)(0.8-0.34285)}{2\times 0.8} = 0.91428$$
$$y^*_{\tilde{\tilde{B}}^U} = \frac{1\times 2.5714}{6} = 0.42857$$
$$x^*_{\tilde{\tilde{B}}^U} = 0.91428$$

Step 3: Compute the COG points $\left(x^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{A}}}\right)$ and $\left(x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{B}}}\right)$

$$x^*_{\tilde{\tilde{A}}} = \frac{A\left(\tilde{\tilde{A}}^U\right)\times x^*_{\tilde{\tilde{A}}^U} - A\left(\tilde{\tilde{A}}^L\right)\times x^*_{\tilde{\tilde{A}}^L}}{A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right)} = \frac{0.11\times 0.8465 - 0.088\times 0.8465}{0.11-0.088} = 0.8465$$

Similarly, by using (Eqs. 3.36-3.39), the following points can be calculated as,

$$y^*_{\tilde{\tilde{A}}} = \frac{0.11\times 0.3823 - 0.088\times 0.3059}{0.11-0.088} = 0.6882$$
$$x^*_{\tilde{\tilde{B}}} = \frac{0.11\times 0.91428 - 0.088\times 0.91428}{0.11-0.088} = 0.9143$$
$$y^*_{\tilde{\tilde{B}}} = \frac{0.11\times 0.42857 - 0.088\times 0.34285}{0.11-0.088} = 0.7714$$

Step 4: Compute $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right)$ and $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)$,

$$\begin{aligned} L\left(\tilde{\tilde{A}}^L\right) &= \sqrt{\left(a_1^L - a_2^L\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^L}} + \sqrt{\left(a_3^L - a_4^L\right)^2 + \hat{w}^2_{\tilde{\tilde{A}}^L}} + \left(a_3^L - a_2^L\right) + \left(a_4^L - a_1^L\right), \\ &= \sqrt{(0.75-0.84)^2 + (0.8)^2} + \sqrt{(0.89-0.92)^2 + (0.8)^2} + (0.89-0.84) + (0.92-0.75) \\ &= 2.1171 \end{aligned}$$

$$L\left(\tilde{\tilde{B}}^{L}\right)=\sqrt{(0.84-0.88)^{2}+(0.8)^{2}}+\sqrt{(0.96-0.98)^{2}+(0.8)^{2}}+(0.96-0.88)+(0.98-0.84)$$
$$=2.1802$$

From Eq. 3.40,

$$S\left(\tilde{\tilde{A}}^{L},\tilde{\tilde{B}}^{L}\right)=\left[1-\left(\frac{0.26}{4}\right)\right]\times\frac{2.1171+0.8}{2.1802+0.8}=0.9152$$

Similarly,

$$L\left(\tilde{\tilde{A}}^{U}\right)=\sqrt{\left(a_1^U-a_2^U\right)^2+\hat{w}^2_{\tilde{\tilde{A}}^U}}+\sqrt{\left(a_3^U-a_4^U\right)^2+\hat{w}^2_{\tilde{\tilde{A}}^U}}+\left(a_3^U-a_2^U\right)+\left(a_4^U-a_1^U\right),$$
$$=\sqrt{(0.75-0.84)^{2}+(1)^{2}}+\sqrt{(0.89-0.92)^{2}+(1)^{2}}+(0.89-0.84)+(0.92-0.75)=2.4704$$

$$L\left(\tilde{\tilde{B}}^{U}\right)=\sqrt{(0.84-0.88)^{2}+(1)^{2}}+\sqrt{(0.96-0.98)^{2}+(1)^{2}}+(0.96-0.88)+(0.98-0.84)=2.5262$$

Now, from Eq. 3.43,

$$S\left(\tilde{\tilde{A}}^{U},\tilde{\tilde{B}}^{U}\right)=\left[1-\left(\frac{0.26}{4}\right)\right]\times\frac{2.4704+1}{2.5262+1}=0.9202$$

Step 5: Compute Δx and Δy using Eqs. 3.46, 3.47

$$\Delta x=|0.8465-0.9143|=0.0678$$
$$\Delta y=|0.6882-0.7714|=0.0832$$

Step 6: Compute the degree of similarity $S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)$

From Eq. 3.48, where t=1 and u=0

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=\left[\frac{0.9152+0.9202}{2}\times(1-0.0678)\times(1-0.0832)\right]^{\left(\frac{1}{3}\right)}\times 1$$
$$=0.922$$

3.1.2.10 Concluding Remarks

In the preceding study an efficient fuzzy-based decision-model has been reported towards agility appraisement for an integrated supply chain. To avoid uncertainty-vagueness arising from decision-makers subjective judgment on tangible and intangible agile criteria/attributes, use of fuzzy linguistic representation has been recommended. Degree of accuracy of this compromise decision-making process has been aimed to be increased by adopting Interval-Valued fuzzy numbers. A Fuzzy Agility Index has been computed and considered as an overall evaluation index representing extent of supply chain agility. '*Degree of Similarity*' concept (between two fuzzy numbers) adopted from '*Fuzzy Risk Analysis*' has been articulated in this study to rank various agile criteria and consequently to identify weak agile criterions. The supply chain agility level can be boost up by improving performances of those weak segments in the supply chain.

Table 3.13: Definitions of linguistic variables for criteria ratings and weights (A-9 member interval linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized interval-valued trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	[(0, 0, 0, 0; 0.8), (0, 0, 0, 0; 1)]
Very Poor (VP)	Very Low (VL)	[(0, 0, 0.02, 0.07; 0.8), (0, 0, 0.02, 0.07; 1)]
Poor (P)	Low (L)	[(0.04, 0.10, 0.18, 0.23; 0.8), (0.04, 0.10, 0.18, 0.23; 1)]
Medium Poor (MP)	Medium Low (ML)	[(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1)]
Medium (M)	Medium (M)	[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1)]
Medium Good (MG)	Medium High (MH)	[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1)]
Good (G)	High (H)	[(0.72, 0.78, 0.92, 0.97; 0.8), (0.72, 0.78, 0.92, 0.97; 1)]
Very Good (VG)	Very High (VH)	[(0.93, 0.98, 1, 1; 0.8), (0.93, 0.98, 1, 1; 1)]
Absolutely Good (AG)	Absolutely High (AH)	[(1, 1, 1, 1; 0.8), (1, 1, 1, 1; 1)]

Table 3.21: Ranking order of agile criterions (based on fuzzy Degree of Similarity concept)

Agile Criteria (Grade III) (C_{ijk})	$S(\tilde{\tilde{A}}, \tilde{\tilde{B}})$	Ranking Order
C_{111}	0.922	***8***
C_{112}	0.911	***9***
C_{113}	0.932	***6***
C_{121}	0.894	***12***
C_{122}	0.930	***7***
C_{123}	0.894	***12***
C_{131}	0.939	***4***
C_{132}	0.945	***2***
C_{211}	0.922	***8***
C_{212}	0.911	***9***
C_{213}	0.911	***9***
C_{221}	0.785	***15***
C_{222}	0.843	***13***
C_{23}	0.904	***11***
C_{31}	0.907	***10***
C_{321}	0.948	***1***
C_{322}	0.934	***5***
C_{323}	0.943	***3***
C_{324}	0.922	***8***
C_{33}	0.798	***14***

3.1.3 Agility Appraisement in MC Product Manufacturing

3.1.3.1 Overview

In today's business scenario, enterprises have become more concerned towards mass customization (MC), providing a wide variety of products that satisfy customers' specific requirements. Enormous product variety invites escalating costs and complexity in manufacturing context. In order to respond to the mass customization trend; it is felt indeed necessary to develop an agility-based manufacturing system to embrace the traits involved in MC. Agility index of mass customization and the management and technology dimension associated with the specific system are really helpful to deal with the critical elements of implementing MC.

To this end, the present work highlights on an MC product manufacturing agility evaluation approach based on the characteristics of MC product manufacturing and the requirement of agile manufacturing, by considering (i) MC enterprise's organization management agility evaluation, (ii) MC products design agility evaluation, and (iii) MC manufacture agility evaluation. Interval-Valued Fuzzy Sets (IVFS) has been adopted in this evaluation model. A Fuzzy Agility Index (FAI) has been computed and compared with predefined agility measurement scale to assess the extent of agility in MC product manufacturing.

3.1.3.2 Research Background

3.1.3.2.1 Mass Customization (MC) in Manufacturing/ Production Context

Mass Customization is the new paradigm that replaces mass production, which is no longer suitable for today's turbulent markets, growing product variety, and opportunities for e-commerce. Mass customization proactively manages product variety in the environment of rapidly evolving markets and products, many niche markets, and individually customized products sold through stores or over the internet. Mass customizers can customize products quickly for individual customers or for niche markets at better than mass production efficiency and speed. Using the same principles, mass customizers can 'Build-to-Order' both customized products and standard products without forecasts, inventory, or purchasing delays.

Mass customization, in marketing, manufacturing, call centers and management, is the utilization of flexible computer-aided manufacturing systems to produce custom output. Those systems combine the low unit costs of mass production processes with the flexibility of individual customization. Mass customization is the new frontier in business competition for both manufacturing and service industries. At its core is a tremendous increase in variety and customization without a corresponding increase in costs. At its limit, it is the mass production of individually customized goods and services. At its best, it provides strategic advantage and economic value. Mass customization is the method of effectively postponing the task of differentiating a product for a specific customer until the latest possible point in the supply network (Chase et al., 2006).

The concept of mass customization is attributed as producing goods and services to meet individual customer's needs with near mass production efficiency. It is a strategy that creates value by some form of company-customer interaction at the fabrication and assembly stage of the operations level to create customized products with production cost and monetary price similar to those of mass-produced products. It delivers individually customized products at mass production prices with implementation of late configuration (James, 2005). Agile manufacturing is not about giving consumers' choice but realizing what they actually want. According to (Kidd, 1995), most of the companies have gone down in mass customization road due to the cause of anti-agility characteristics. They provide wider choice to customers by using the techniques of product modularity and standardized components. However, that choice is yet limited, even though it is frequently very large. An agile enterprise should have the capability to deal with such exceptions rapidly and without elevated costs. (James, 2005), concluded an important difference between mass customization and agility is that, mass customization delivers customized products at mass production prices while agility has the ability to respond to change, uncertainty and unpredictability in the business environment, whatever its sources customers, competitors, new technologies, suppliers or government regulation may be.

Mass Customization combines the principles of Lean Manufacturing and Synchronous Manufacturing principles with those of agility, taking full advantage of all three production strategies. Mass Customization differs from Lean Manufacturing and Synchronous Manufacturing in the sense that lean manufacturing is oriented toward a repetitive manufacturing environment with order characteristics of high-volume/low-mix, and synchronous manufacturing applies to low-volume/high mix.

Mass Customization requires an agile supply chain to function optimally. Supply chain agility is the extent of network capability that the organization possesses. Key to the success of an agile supply chain is the speed and flexibility with which these activities can be accomplished and the realization that customer needs and customer satisfaction are the very reasons for the network.

Achieving expected level of customer satisfaction capability requires all physical and logical events within the supply chain to be enacted swiftly, accurately, and effectively. The faster parts, information, and decisions flow through an organization, the faster it can respond to customer needs. The benefits of MC production generally are specialization, high volume flexibility, lower costs, higher quality, lower inventory, and shorter lead times. The characteristics of mass customized production processes are listed below:

i. Make to order
ii. High or low volumes
iii. Low inventories
iv. Short lead times
v. Just-In-Time materials/pull scheduling in early stages
vi. Synchronized scheduling in later stages
vii. Short cycle times
viii. Highly flexible and responsive processes
ix. Highly flexible machines and equipment
x. Quick changeover
xi. Continuous flow work cells
xii. Collocated machines, equipment, tools and people
xiii. Compressed space
xiv. Multi-skilled employees
xv. Empowered employees
xvi. High first-pass yields with major reductions in defects

3.1.3.2.2 Measurement of Agility in MC Product Manufacturing

Most of the literature discussed on the concept towards development of integrated frameworks for agile enterprises towards implementing mass customized product manufacturing. While enhancing agility in the enterprise many questions arise (Gunasekaran, 1991; Sharp et al., 1999; Yusuf et al., 2001; Lin et al., 2006a, b):

1. What is meant by agility precisely and how it can be measured?
2. How and to what degree does the companies attributes affect companies business performance? How can the company identify the major obstacles to improve organizational agility?
3. How to compare organizational agility to competitiveness?
4. How to assist in achieving agility effectively?

To assist managers in better achieving an agile enterprise, there have been numerous studies dedicated to design, implementation and measurement of agility. Agile enterprise design consists of definition and measurement of agile criteria, agile attributes, and agile enablers; how company's attributes affect business performance and identification of principal obstacles towards improvement (Goldman et al., 1995; Yusuf et al., 1999; Sharifi and Zhang, 2001; Hoak et al., 2001; Tsourveloudis and Valavanis, 2002; Sherehiy et al., 2007; Chandna (Kharbanda), 2008; Ganguly et al., 2009; Anuziene and Bargelis, 2010). Agility evaluation attains importance in contemporary industry scenario as it is an indicator of strategic agile position of an organization (Ramesh and Devadasan, 2007; Vinodh et al., 2008; Vinodh et al., 2009, Vinodh et al., 2010a, b, c, d; Vinodh et al., 2011). Agility index (Vinodh et al., 2011) is given by,

$$\text{Agility Index} = \sum_{j=1}^{N} A_{ij} \tag{3.56}$$

Here, A_{ij} is the agility level of capability j of the enterprise i.

$$\text{Agility Index} = \sum_{i=1}^{N} R_i \times w_i \tag{3.57}$$

Here, R_i denote the agility index and w_i the weight of each agile capability, and

$$\sum_{i=1}^{N} w_i = 1 \tag{3.58}$$

In agility assessment, most of the criteria are qualitative in nature which is not completely-defined. Due to the ill-defined and vague indicators which exist within agility assessment, most measures are described subjectively by linguistic terms which are characterized by ambiguity and multi-possibility, and the conventional assessment approaches cannot suitably or effectively handle such measurement (Lin et al., 2006a, b). However, fuzzy logic provides a useful tool for dealing with decisions in which the phenomenon is imprecise, uncertain and vague. Using fuzzy concepts, evaluators (decision-makers) can use linguistic terms to assess indicators in a natural language expression, and each linguistic (subjective judgment) term can be associated with membership function. Fuzzy logic has got wide applications in the process of managerial decision-making and decision-information sciences (Vinodh et al., 2008).

3.1.3.3 Design Adopted for Agility Evaluation of MC Product Manufacturing System

Mass Customization (MC) is an operational strategy focused on inducing velocity and flexibility in a make-to-order production process, with the capability of producing at a minimum, a quantity of one, (or large quantities) with minimal changeovers and interruptions. Mass Customized products can efficiently compete with standard products, providing a company a competitive edge by having the capability to manufacture specialized or custom products at the speed, volume, cost, and quality as standard products.

Based on the rapid obtaining of MC demanded information from the consumers, and market changing information, MC product agile manufacture is to develop new products in responding to the consumers' demands and to guide the markets via agile organization management, agile design as well as agile manufacturing. Accordingly, MC enterprises are required to possess the abilities of agile organization management, product design and product manufacturing. For this reason, it is felt necessary to synthesize these three aspects for carrying out the agility evaluation of MC product manufacturing. The conceptual model for agility evaluation in mass customization product manufacturing system adopted in this work has been furnished in Table 3.22 (Yang and Li, 2002). The model consists of three agile enablers, 10 agile criteria and 23 agile attributes. The model addresses all major dimensions of agility such as MC enterprise organization management agility; MC enterprise products design agility, and MC enterprise processing manufacture agility. The agile enablers form the first level (Grade-I), agile attributes form the second level (Grade-II) and the agile criterions form the third level (Grade-III).

3.1.3.4 Problem Statement

To assist managers in multi-criteria decision making, a model on fuzzy logic provides a means of measuring how agile an enterprise is and how to identify principal obstacles to implement it. Performance ratings and importance weights of different agility indices are to be assessed by the decision-makers (DMs) in linguistic terms. Then appropriate fuzzy numbers are used to represent linguistic values, and simple fuzzy arithmetic operations are employed to synthesize these fuzzy numbers into a unique fuzzy number called Fuzzy Agility Index (FAI). FAI is matched with appropriate linguistics, thereby enabling the agility level to be expressed in linguistic terms (Lin et al., 2006a, b). However, conventional fuzzy set theory is not accurate enough in dealing with subjective judgment of DMs individual perceptions. In order to overcome this, Interval-Valued Fuzzy Set (IVFS) theory has been proposed here to develop a logical and systematic approach for agility evaluation and appraisement for a mass customized product manufacturing system. The IVFNs have been utilized for transforming DMs linguistic judgment into corresponding fuzzy numbers. In order to refine linguistic data (decision-makers opinions) in an efficient manner, and to enhance the degree of accuracy of existing conventional fuzzy based approaches, Interval Valued Fuzzy Set (IVFS) theory has been attempted and proved fruitful to a larger extent.

3.1.3.5 Procedural Hierarchy

Agility evaluation has been made by the procedural framework as described as follows (Vinodh et al., 2011). The various steps adopted here have been presented in block diagram given in Fig. 3.3. This agility evaluation framework has been empirically case studied.

1 Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of agile attributes

The linguistic terms are used to assess the performance ratings and priority weights of agile attributes since it is difficult for the decision-makers to determine the score of a vague attribute. The linguistic scale used by (Wei and Chen, 2009) has been adopted in this study. In order to assess the performance rating of the agile criterions from Table 3.22 (in Grade-III), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used. In order to assess the importance weights (priority degree) of the agile indices, the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized. The linguistic variables have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation (Table 3.23).

2 Measurement of performance ratings and importance weights of agile attribute using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of agile attributes has been assumed agreed by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales to assess the performance rating as well as to assign importance weights (Appendix: Tables 3.24-3.27).

3 Approximation of the linguistic terms by fuzzy IVF numbers

Using the concept of Interval-Valued Fuzzy Set (IVFS) theory, the linguistic variables have been be approximated by IVFNs (trapezoidal, in the present case). Next, the aggregated decision-making cum evaluation matrix has been constructed and shown in Appendix (Table 3.28).

4 Determination of FAI

FAI represents the overall enterprise level agility (Lin et al., 2006a, b). The fuzzy index has been calculated at the criterion level and then extended to enabler level. Fuzzy index at the criterion level encompasses several agile attributes. The fuzzy index of Grade-II agile attributes (Appendix: Table 3.29) can be calculated using the formula:

$$U_{ij} = \frac{\sum_{k=1}^{n}\left(w_{ijk} \otimes U_{ijk}\right)}{\sum_{k=1}^{n} w_{ijk}} \tag{3.59}$$

Here, U_{ijk} represent performance rating and w_{ijk} represent fuzzy weight for priority importance corresponding to agile criterions.

The fuzzy index of Grade-I agile capabilities (Appendix: Table 3.30) can be calculated using the formula:

$$U_{i} = \frac{\sum_{j=1}^{n}\left(w_{ij} \otimes U_{ij}\right)}{\sum_{j=1}^{n} w_{ij}} \tag{3.60}$$

Here, U_{ij} represent performance rating and w_{ij} represent fuzzy weight for priority importance corresponding to agile attributes.

Overall Fuzzy Agility Index (FAI) can be computed as:

$$FAI = \frac{\sum_{i=1}^{n}\left(w_{i} \otimes U_{i}\right)}{\sum_{i=1}^{n} w_{i}} \tag{3.61}$$

Here, U_{i} represent performance rating and w_{i} represent fuzzy weight for priority importance corresponding to agile capabilities. Overall fuzzy agility index:

$$FAI =$$

$$\left[(3.24,4.00,6.09,6.95;0.8),(3.24,4.00,6.09,6.95;1)\right] \otimes \left[(0.96,0.99,1.00,1.00;0.8),(0.96,0.99,1.00,1.00;1)\right]$$
$$\oplus \left[(3.86,4.51,5.71,6.14;0.8),(3.86,4.51,5.71,6.14;1)\right] \otimes \left[(0.89,0.93,0.98,0.99;0.8),(0.89,0.93,0.98,0.99;1)\right]$$
$$\oplus \left[(4.32,5.09,6.66,7.22;0.8),(4.32,5.09,6.66,7.22;1)\right] \otimes \left[(0.82,0.88,0.96,0.98;0.8),(0.82,0.88,0.96,0.98;1)\right]$$

$$FAI = [(10.14, 12.66, 18.08, 20.16; 0.8), (10.14, 12.66, 18.08, 20.16; 1)]$$

5 Determination of Euclidean distance to match FAI with approximate agility level

Computed score of FAI has to be matched with an appropriate agility level decided by the top management based on a predefined agility scale (extent of agility scale). It has been mentioned in the literature that *Euclidean distance method* is the most widely used method for matching the membership function with linguistic terms. The advantage of Euclidean distance method is the most intuitive form of human perception of proximity (Lin et al., 2006). In this case, the natural level expression set AL = ***{Definitely agile (DA), Extremely agile (EA), Very agile (VA), Highly Agile (HA), Agile (A), fairly Agile (FA), Slightly Agile (SA), Lowly Agile (LA), Slowly (S)}*** (Table 3.31) has been selected for labelling.

Say, an IVFS A in X is given by,

$A = \{< x, M_A(x) > / x \in X\}$, where $M_A : X \rightarrow D[0,1]$, $M_A(x)$ denotes the degree of membership of the element x to the set A.

Let A and B be two IVFSs, the Euclidean distance between two A and B be two IVFSs in X is:

$$d_{EIVFS}(A, B) = \sqrt{\sum_{i=1}^{n} \frac{(M_{AL}(x_i) - M_{BL}(x_i))^2 + (M_{AU}(x_i) - M_{BU}(x_i))^2}{2}} \tag{3.62}$$

The normalized Euclidean distance is:

$$d'_{EIVFS}(A, B) = \frac{d_{EIVFS}(A, B)}{\sqrt{n}} \tag{3.63}$$

Euclidean distance method has been used to find the distance d from the FAI to each member in set AL and calculated as follows:

$$d(FAI, AL_i) = \left\{ \sum_{x \in p} [f_{FAI}(x) - f_{ALi}(x)]^2 \right\}^{0.5} \tag{3.64}$$

By matching a linguistic label with the minimum d, the agility index has been identified as *'very agile'*.

$d(FAI, DA) = 10.143$

$d(FAI, EA) = 10.214$

$d(FAI, VA) = 10.285$

$d(FAI, HA) = 10.356$

$d(FAI, A) = 10.426$

$d(FAI, FA) = 10.497$

$d(FAI, SA) = 10.568$

$d(FAI, LA) = 10.638$

$d(FAI, S) = 10.709$

3.1.3.6 Managerial Implications

Today's market is going on very complex and volatile. Satisfying customers' demand is the main motto for every success business entrepreneur and also the manufacturing industries. To cope up this challenge, agile manufacturing is focused to be the emerging concept rather than existing ones. Abrupt change, uncertainty and unpredictability in the global business environment is rendering invalid many of these existing assumptions as well as elements of current practices being pursued. Most of the pioneer researcher focused on defining agility based on current practices; but the precise in-depth understandings of agility, reviewing at what organizations has been implemented yet over the past twenty years and also what companies are expected to cope up in upcoming future that is extremely important.

Literature depicts that pioneers contributed and added value towards development of different approaches for measuring agility. Since conventional agility measurement is associated with vagueness and complexity, arises from subjective judgment of the decision-makers; fuzzy logic approach is seemed helpful in this context (Qureshi et al., 2009; Singh et al., 2010). However, conventional fuzzy approach is not reliable enough to that extent. Therefore, Interval-Valued Fuzzy Sets (IVFS) has been explored in the present work to frame a conceptual model for agility assessment. This approach accumulates the opinion for ratings and assigned attribute priority weights from a group of experts (decision-makers). The agility index has been computed. Based on Euclidean distance computation, the empirical organization has been found to be '*Definitely agile*'.

3.1.3.7 Concluding Remarks

The conceptual framework for the agility index appraisement system based on IVFS has been illustrated and applied in an empirical study. The agility assessment method (in the context of MC product manufacturing) can be used as a test kit for periodically evaluating agility level of the organization. This kind of exercise would enable the organization to identify the competitive strengths and weaknesses which is vital in today's competitive business scenario.

The adaptation of IVFS in agility index evaluation system is the contribution of this work. IVFS with higher degree of reliability can efficiently be utilized for solving complicated decision making problems. However, the disadvantage of IVFS is only the complexity followed by tedious time-consuming computations.

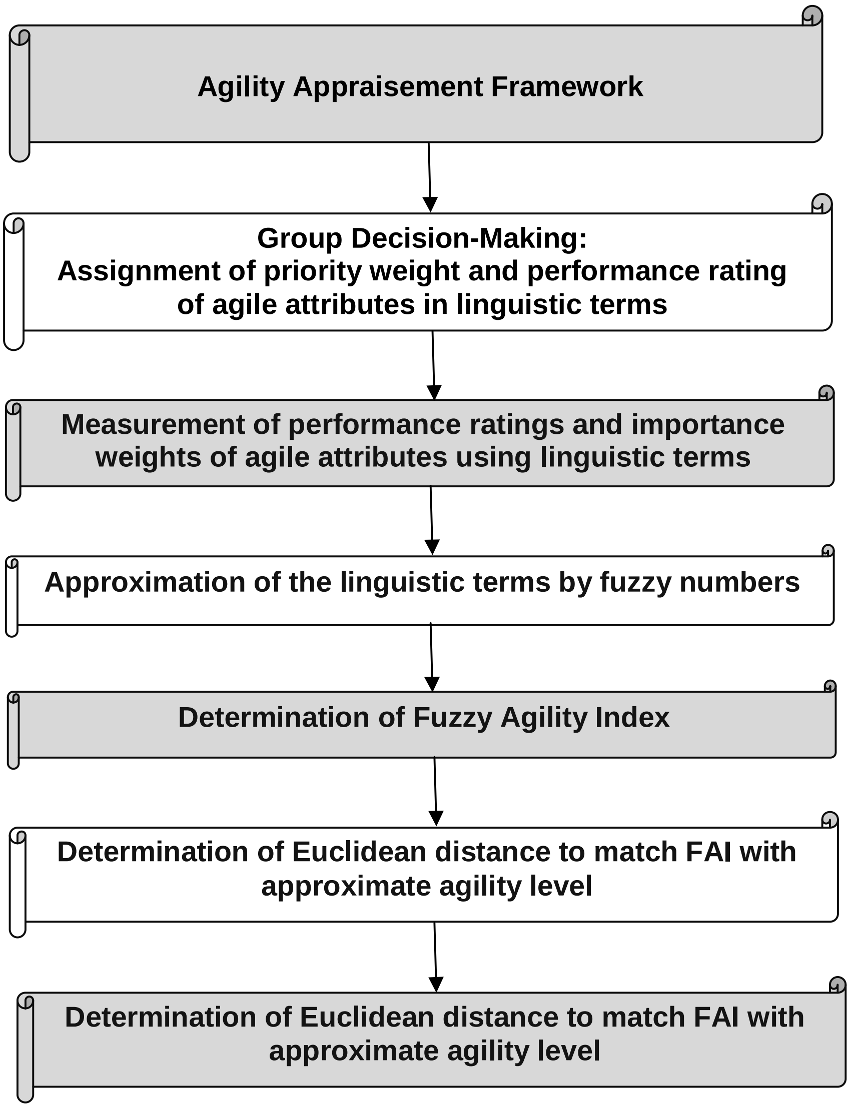

Fig. 3.3: Agility measurement appraisement framework

Table 3.22: Agility evaluation index system of MC product manufacturing (Yang and Li, 2002)

I-Grade index	II-Grade index	III-Grade index
MC enterprise organization management agility (U_1)	Information management agility (U_{11})	Perfect degree of enterprise information system (U_{111})
		Network connection extensiveness (U_{112})
		Information and network utilization rate (U_{113})
	Inter-organization cooperative extent (U_{12})	The degree of cooperating with other enterprises (U_{121})
		The application degree of the VE (U_{122})
	Produce organizing agility (U_{13})	The space organizational form of the production process (U_{131})
		The time organizational form of the production process (U_{132})
	The agility of institutional framework (U_{14})	The form of institutional framework (U_{141})
		Speediness of team building (U_{142})
MC enterprise products design agility (U_2)	Customer demand information getting agility (U_{21})	The way of demand information got (U_{211})
		The proportion of information processing time in products period (U_{212})
	Speediness of product design (U_{22})	The period of product design (U_{221})
		The proportion of design period in products period (U_{222})
	Product design flexibility (U_{23})	The seriating degree of products (U_{231})
		The similar degree of products structure (U_{232})
		The universalization degree of the part (U_{233})
MC enterprise organization processing manufacture agility (U_3)	Re-configurable (U_{31})	Packaging integrated unit modular (U_{311})
		Supplement tool displacement (U_{312})
		Displacement compatibility (U_{313})
	The speed of manufacture (U_{32})	The proportion of production and technology preparing time in products period (U_{321})
		The period of manufacture (U_{322})
		The proportion of manufacture period in products period (U_{323})
	Manufacturing flexibility (U_{33})	The universalization degree of the equipment (U_{331})
		The scalable degree of the equipment (U_{332})

Table 3.23: Definitions of linguistic variables for criteria ratings and priority weights (A-9 member linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized interval-valued trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	[(0, 0, 0, 0; 0.8), (0, 0, 0, 0; 1)]
Very Poor (VP)	Very Low (VL)	[(0, 0, 0.02, 0.07; 0.8), (0, 0, 0.02, 0.07; 1)]
Poor (P)	Low (L)	[(0.04, 0.10, 0.18, 0.23; 0.8), (0.04, 0.10, 0.18, 0.23; 1)]
Medium Poor (MP)	Medium Low (ML)	[(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1)]
Medium (M)	Medium (M)	[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1)]
Medium Good (MG)	Medium High (MH)	[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1)]
Good (G)	High (H)	[(0.72, 0.78, 0.92, 0.97; 0.8), (0.72, 0.78, 0.92, 0.97; 1)]
Very Good (VG)	Very High (VH)	[(0.93, 0.98, 1, 1; 0.8), (0.93, 0.98, 1, 1; 1)]
Absolutely Good (AG)	Absolutely High (AH)	[(1, 1, 1, 1; 0.8), (1, 1, 1, 1; 1)]

Table 3.31: Definitions of linguistic variables to identify agility level ratings (A-9 member linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Generalized interval-valued trapezoidal fuzzy numbers
Definitely Agile (DA)	[(0.8, 0.9, 0.9, 1.0; 1), (0.8, 0.9, 0.9, 1.0; 1)]
Extremely Agile (EA)	[(0.7, 0.8, 0.8, 0.9; 1), (0.7, 0.8, 0.8, 0.9; 1)]
Very Agile (VA)	[(0.6, 0.7, 0.7, 0.8; 1), (0.6, 0.7, 0.7, 0.8; 1)]
Highly Agile (HA)	[(0.5, 0.6, 0.6, 0.7; 1), (0.5, 0.6, 0.6, 0.7; 1)]
Agile (A)	[(0.4, 0.5, 0.5, 0.6; 1), (0.4, 0.5, 0.5, 0.6; 1)]
Fairly Agile (FA)	[(0.3, 0.4, 0.4, 0.5; 1), (0.3, 0.4, 0.4, 0.5; 1)]
Slightly Agile (SA)	[(0.2, 0.3, 0.3, 0.4; 1), (0.2, 0.3, 0.3, 0.4; 1)]
Lowly Agile (LA)	[(0.1, 0.2, 0.2, 0.3; 1), (0.1, 0.2, 0.2, 0.3; 1)]
Slowly (S)	[(0.0, 0.1, 0.1, 0.2; 1), (0.0, 0.1, 0.1, 0.2; 1)]

3.2 Agility Appraisement in Grey Context

This section aims at developing an efficient agility appraisement module in grey environment. Incorporation of the theory of grey relation, grey numbers, and grey possibility degree has been presented here to facilitate agility appraisement decision-making.

3.2.1 Overview

Agile Manufacturing is oriented toward low-volume/high mix, adding velocity and flexibility in the production process. It applies to environments where customized, configurable, or specialized orders, offer a competitive advantage. Agile Manufacturing requires an agile supply chain to function optimally. Towards successful implementation of agility, performance appraisal has become a key strategic consideration for the industrialists as well as business practitioners. An appraisement index system is essential to estimate existing agility extent in an industrial context/ organizational supply chain. To this end, present work highlights an efficient agility measurement platform using the concept of grey numbers theory. Detailed methodology has been illustrated and the said appraisement platform has been analyzed through an empirical study.

3.2.2 Background and Problem Statement

Changing customer and technological requirements force manufacturers to develop agile supply chain capabilities in order to be competitive. Therefore, several companies are stressing flexibility and agility in order to respond, real time, to the unique needs of customers and markets (Yusuf et al., 2004).

Agility refers to the capability of an organization to respond quickly in accordance with the dynamic demands of the customers (Vinodh et al., 2010a, b, c, d). While implementing agility, evaluation of performance metric is indeed very important. Literature depicts extensive research attempted by pioneer researchers on agile system modeling as well as performance appraisement.

Rachel and Denis (1999) provided a Route-Map indicating the steps to be taken in achieving supply chain agility in real world scenarios. Lin et al. (2006a, b) developed a fuzzy agility index (FAI) based on agility providers using fuzzy logic. The proposed FAI comprised attribute' ratings and corresponding weights, and was aggregated by a fuzzy weighted average. To illustrate the efficacy of the method, the authors also evaluated the supply chain agility of a Taiwanese company. Kaveh et al. (2011) proposed a hybrid approach to measure the relative efficiency of agility in supply chains. First, a conceptual model including capabilities and providers of agility in supply chains was represented. Then, a supply chain was associated to a Decision Making Unit (DMU) which consumed providers of agility to produce capabilities of agility. A Fuzzy Data Envelopment Analysis (FDEA) was proposed for measuring the efficiency of transformation process in which a given supply chain transforms providers of agility into capabilities of agility.

Radfar et al. (2011) presented a model for evaluating agility in supply chain of two dominant telecommunication companies in Iran. To avoid any ambiguities which were caused by linguistic methods; in this evaluation model the authors used Fuzzy Inference System (FIS) which is neither stochastic nor random. Somuyiwa et al. (2011) analyzed the role of information system (IS) capabilities in achieving supply chain agility in manufacturing firms. The result revealed that an organization's supply chain agility through its information system capabilities had a positive influence on its supply chain performance. Karuppusami et al. (2011) proposed 'TADS' approach in achieving supply chain agility. Zandi and Tavana (2011) presented a novel structured approach to evaluate and select the best agile (electronic customer relationship management) e-CRM framework in a rapidly changing manufacturing environment. Tseng and Lin (2011) suggested a new agility development method for dealing with the interface and alignment issues among the agility drivers, capabilities and providers using the QFD relationship matrix and fuzzy logic. A Fuzzy Agility Index (FAI) for an enterprise composed of agility capability ratings and a total relation-weight with agility drivers was developed to measure the agility level of an enterprise. Vinodh et al. (2012) presented a thirty-criterion agility assessment model which could be utilized to measure agility and to identify the agile characteristics of organization. Thus, weak factors were identified, and proposals were suggested so as to enhance the organizational agility.

Apart from fuzzy logic, grey relation theory has the capability to deal with incomplete, inconsistent and vague information against subjective evaluation criteria. Successful application of grey theory (exploration of grey numbers) has been found in literature (Li et al., 2007a, b; Li et al., 2010; Xu and Sasaki, 2004; Jadidi et al., 2008) in a variety of decision-making situations. Grey theory (Deng, 1982), originally developed by *Prof. Deng* in 1982, has become a very effective method of solving uncertainty problems under discrete data and incomplete information. Grey theory has now been applied to various areas such as forecasting, system control; decision-making and computer graphics. The basic definitions regarding relevant mathematical background of grey system, grey set and grey number in grey theory were presented in the work by Xia (2000).

Therefore, grey numbers theory has been adapted in this part of work to facilitate such a decision-modelling in agile manufacturing context. The grey based appraisement platform presented here yields an overall grey performance index towards agility assessment in organizational supply chain and indentifies week performing areas for future improvement.

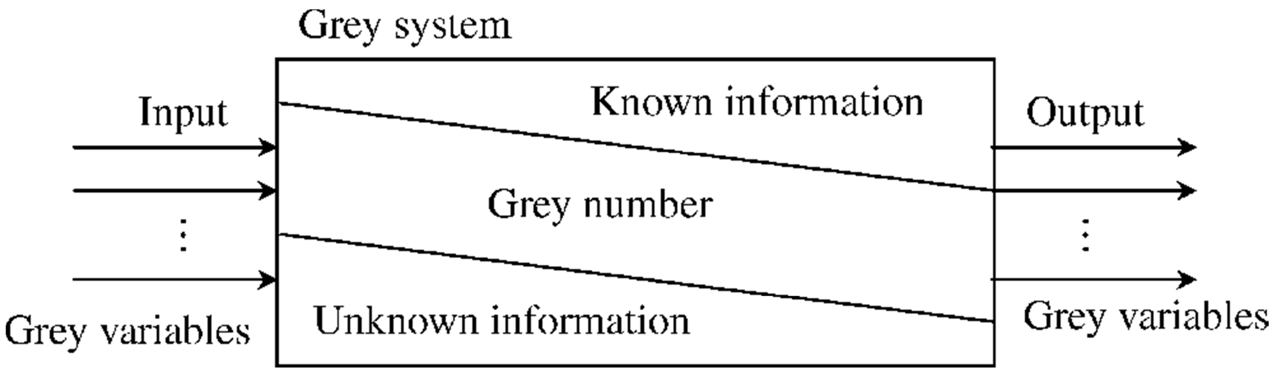

Fig. 3.4: The concept of a grey system

3.2.3 Theory of Grey Numbers: Mathematical Basis

Grey theory (Deng, 1982), originally developed by Prof. Deng in 1982, has become a very effective method of solving uncertainty problems under discrete data and incomplete information. Grey theory has now been applied to various areas such as forecasting, system control, decision-making and computer graphics. Here, we give some basic definitions regarding relevant mathematical background of grey system, grey set and grey number in grey theory.

Definition 1: A grey system (Xia, 2000) is defined as a system containing uncertain information presented by grey number and grey variables. The concept of grey system is shown in Fig. 3.4.

Definition 2: Let X be the universal set. Then a grey set G of X is defined by its two mappings

$$\begin{cases} \overline{\mu}_G(x):\ x \to [0,1] \\ \underline{\mu}_G(x):\ x \to [0,1] \end{cases}$$

$\overline{\mu}_G(x) \geq \underline{\mu}_G(x), x \in X,\ X = R,\ \overline{\mu}_G(x)$ and $\underline{\mu}_G(x)$ are the upper and lower membership functions in G respectively. When $\overline{\mu}_G(x) = \underline{\mu}_G(x)$, the grey set G becomes a fuzzy set. It shows that grey theory considers the condition of fuzziness and can flexibly deal with the fuzziness situation.

Definition 3: A grey number is one of which the exact value is unknown, while the upper and/or the lower limits can be estimated. Generally grey number is written as $\left(\otimes G = G\big|_{\underline{\mu}}^{\overline{\mu}}\right)$.

Definition 4: If only the lower limit of G can be possibly estimated and G is defined as lower limit grey number.

$$\otimes G = [\underline{G}, \infty] \tag{3.65}$$

Definition 5: If only the upper limit of G can be possibly estimated and G is defined as lower limit grey number.

$$\otimes G = [-\infty, G] \tag{3.66}$$

Definition 6: If the lower and upper limits of G can be estimated and G is defined as interval grey number.

$$\otimes G = [\underline{G}, \overline{G}] \tag{3.67}$$

Definition 7: The basic operations of grey numbers $\otimes G_1 = [\underline{G}_1, \overline{G}_1]$ and $\otimes G_2 = [\underline{G}_2, \overline{G}_2]$ can be expressed as follows:

$$\otimes G_1 + \otimes G_2 = [\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2] \tag{3.68}$$

$$\otimes G_1 - \otimes G_2 = [\underline{G}_1 - \underline{G}_2, \overline{G}_1 - \overline{G}_2] \tag{3.69}$$

$$\begin{gathered}\otimes G_1 \times \otimes G_2 = [\underline{G}_1, \overline{G}_1] \times [\underline{G}_2, \overline{G}_2] = \\ [Min.(\underline{G}_1 \underline{G}_2, \underline{G}_1 \overline{G}_2, \overline{G}_1 \underline{G}_2, \overline{G}_1 \overline{G}_2), Max.(\underline{G}_1 \underline{G}_2, \underline{G}_1 \overline{G}_2, \overline{G}_1 \underline{G}_2, \overline{G}_1 \overline{G}_2)]\end{gathered} \tag{3.70}$$

$$\otimes G_1 \div \otimes G_2 = [\underline{G}_1, \overline{G}_1] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\overline{G}_2}\right] \tag{3.71}$$

Definition 8: The length of grey number $\otimes G$ is defined as:

$$L(\otimes G) = [\overline{G} - \underline{G}] \tag{3.72}$$

Grey possibility degree is utilized to compare the ranking of grey numbers.

Definition 9: For two grey numbers $\otimes G_1 = [\underline{G}_1, \overline{G}_1]$ and $\otimes G_2 = [\underline{G}_2, \overline{G}_2]$, the possibility degree of $\otimes G_1 \leq \otimes G_2$ can be expressed as follows (Shi et al., 2005):

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{Max.(0, \overline{G}_1 - \underline{G}_2)}{L^*} \tag{3.73}$$

Here, $L^* = L(\otimes G_1) + L(\otimes G_2)$.

For the position relationship between $\otimes G_1$ and $\otimes G_2$, there exists four possible cases on the real number axis. The relationship between $\otimes G_1$ and $\otimes G_2$ are determined as follows:

A. If $\underline{G}_1 = \underline{G}_2$ and $\overline{G}_1 = \overline{G}_2$, we say that $\otimes G_1 = \otimes G_2$ .Then $P\{\otimes G_1 \le \otimes G_2\} = 0.5$.

B. If $\underline{G}_2 = \overline{G}_1$, we say that $\otimes G_2$ is larger than $\otimes G_1$, denoted as $\otimes G_2 > \otimes G_1$.
Then $P\{\otimes G_1 \le \otimes G_2\} = 1$.

C. If $\overline{G}_2 < \underline{G}_1$, we say that $\otimes G_2$ is smaller than $\otimes G_1$, denoted as $\otimes G_2 < \otimes G_1$,
Then $P\{\otimes G_1 \le \otimes G_2\} = 0$.

D. If there is an intercrossing part in them, when $P\{\otimes G_1 \le \otimes G_2\} = 0.5$, we say that $\otimes G_2$ is larger than $\otimes G_1$ denoted as $(\otimes G_2 > \otimes G_1)$. When $P\{\otimes G_1 \le \otimes G_2\} < 0.5$ we say that $\otimes G_2$ is smaller than $\otimes G_1$, denoted as $(\otimes G_2 < \otimes G_1)$.

3.2.4 Proposed Appraisement Platform

Agility evaluation has been made by the procedural framework as described as follows. The evaluation framework has been explored based on an agile capability-attribute-criterion hierarchy (Table 3.32) adapted from the work by Radfar et al., (2011). An approach based on the concept of grey numbers as well as grey possibility degree has been utilized to evaluate an overall agility metric.

In order to deal with subjective performance estimates as well as priority weights of various agile elements (parameters), linguistic variables have been utilized; represented further by transforming into grey numbers. Here, these linguistic variables corresponding to priority weight assignment $\otimes w$ have been expressed in grey numbers by 1-7 scale as shown in Table 3.33. The criterion ratings $\otimes G$ can be also expressed in grey numbers by 1-7 scale shown in Table 3.34.

1 Determination of the appropriate linguistic scale for assessing the performance ratings of agile criterions and importance weights of agile criterions-attributes-capabilities

The linguistic terms (Tables 3.33-3.34) have been used to assess the performance ratings and priority weights of agile criteria-attributes since vagueness is associated with individuals' subjective opinion, it is found difficult for the decision-makers to determine the exact numeric score against a vague attribute. To assign importance weights (priority degree) of the agile capabilities-attributes and criterions, the linguistic variables {***Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH)***} have been utilized (Table 3.33). In order to assess the performance rating of the agile criterions from Table 3.32 (3rd level indices), the seven linguistic variables {***Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG)***} have been used (Table 3.34).

2 Measurement of performance ratings against each of the agile criterions and importance weights of agile capabilities-attributes-criterions using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of agile parameters has been assumed accepted by the decision-makers (DMs), the expert team has been requested to use aforesaid linguistic scales to assess the performance rating as well as to assign importance weights (Appendix: Tables 3.35-3.38).

3 Approximation of the linguistic terms by grey numbers

Decision-makers subjective judgment has been transformed into grey numbers. Assume that a decision-making group has K members; then the criterion weight of criterion Q_j can be calculated as:

$$\otimes w_j = \frac{1}{K}\left[\otimes w_j^1 + \otimes w_j^2 + \ldots + \otimes w_j^K\right] \tag{3.74}$$

Here $\otimes w_j^K\left(j = 1, 2, \ldots, n\right)$ is the attribute weight of k_{th} DM and can be described by grey number $\otimes w_j^K = \left[\underline{w}_j^K, \overline{w}_j^K\right]$

Linguistic variables for the ratings to make attribute rating value have been converted into grey numbers. Then the rating value can be calculated as:

$$\otimes G_{ij} = \frac{1}{K}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + \ldots + \otimes G_{ij}^K\right] \tag{3.75}$$

Here $\otimes G_{ij}^{K}\left(i=1,2,...,m;\ j=1,2,...,n\right)$ is the attribute rating value of K_{th} DM and can be described by grey number $\otimes G_{ij}^{K} = \left[\underline{G}_{ij}^{K}, \overline{G}_{ij}^{K}\right]$.

4 Determination of OGPI

OGI represents *Overall Grey Performance Index*. The grey index has been calculated at the criteria level; then extended to the attribute level and finally to the enabler (capability) level. Grey index system at 2nd level encompasses several agile attributes.

The grey index of 2nd level green attributes can be calculated as follows:

$$U_{i,j} = \frac{\sum_{k=1}^{n}\left(w_{i,j,k} \otimes U_{i,j,k}\right)}{\sum_{k=1}^{n} w_{i,j,k}} \tag{3.76}$$

Here $U_{i,j,k}$ represent aggregated grey performance measure (rating) and $w_{i,j,k}$ represent aggregated grey weight corresponding to agile criterion $C_{i,j,k}$ which is under j_{th} agile attribute (at 2nd level) and i_{th} agile capability (at 1st level).

The grey index of each agile capability/enabler (at 1st level) has been calculated as follows:

$$U_{i} = \frac{\sum_{j=1}^{n}\left(w_{i,j} \otimes U_{i,j}\right)}{\sum_{j=1}^{n} w_{i,j}} \tag{3.77}$$

Here $U_{i,j}$ represent computed grey performance measure (rating) obtained using Eq. 3.76 and $w_{i,j}$ represent aggregated grey weight for priority importance corresponding to j_{th} agile attribute $C_{i,j}$ which is under i_{th} agile capability (at 1st level).

Thus, overall grey performance index $U\left(OGPI\right)$ has been calculated as follows:

$$U\left(OGPI\right) = \frac{\sum_{i=1}^{n}\left(w_{i} \otimes U_{i}\right)}{\sum_{i=1}^{n} w_{i}} \tag{3.78}$$

Here U_{i} = Computed grey performance rating of i^{th} agile capability C_{i} (computed by Eq. 3.77); w_{i} = Aggregated grey weight of i^{th} agile capability, and $i = 1,2,3,...n$.

Aggregated grey performance ratings as well as aggregated weight against each of the agile criterions (at 3rd level) have been obtained (Appendix: Table 3.39). The grey appropriateness ratings of different agile attributes (at 2nd level) with corresponding aggregated weight have been computed next (Appendix: Table 3.40). Similarly computed grey appropriateness ratings of different agile capabilities (at 1st level) with corresponding aggregated weight have thus been obtained (Appendix: Table 3.41). Finally, Eq. 3.78 has been explored to calculate overall agile estimate.

The OGPI thus becomes: [2.183, 18.420]

After evaluating OGPI and the organizational existing agility extent, simultaneously it is also felt indeed necessary to identify and analyze the obstacles called agile barriers (ill-performing areas). Grey Performance Importance Index (GPII) may be used to identify these obstacles. GPII combines the performance rating and importance weight of agile criterions. The higher the GPII of a factor, the higher is the contribution. The GPII can be calculated as follows:

$$GPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \tag{3.79}$$

Here, $w'_{i,j,k} = \left[(1,1) - w_{i,j,k}\right]$ (3.80)

In this formulation, $U_{i,j,k}$ represent aggregated grey performance measure (rating) and $w_{i,j,k}$ represent aggregated grey weight corresponding to agile criterion $C_{i,j,k}$ which is under j_{th} agile attribute (at 2nd level) and i_{th} agile capability (at 1st level).

GPII need to be ranked to identify individual criterion performance level. Based on that poorly performing criterions are identified and in future, attention must be given to improve those criteria aspects in order to boost up overall leanness degree.

Grey Performance Importance Index (GPII) has been computed against each of the agile criterion and furnished in Table 3.42. The concept of 'grey possibility' degree has been explored to identify ill-performing areas towards successful agile implementation practices. Grey possibility degree between GPII of individual agile criterion has thus been computed with reference to the '*ideal GPII*' value [2.52, 4.80]. Lesser value of grey possibility degree corresponds to higher degree of performance. In other words, well performing attributes can be said to contribute more to the overall grey performance estimate. By this way, agile criterions have been ranked accordingly (Table 3.42) and thus, improvement opportunities have been verified.

3.2.5 Concluding Remarks

Agile paradigm has become an important avenue in recent times. Many organizations around the world have been attempting to implement agile concepts. The agility metric is an important indicator in agile performance measure. Aforesaid study aimed to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of agile practices by exploring the concept of grey numbers. The procedural hierarchy presented here could help the industries to assess their existing agile performance extent, to compare and to identify week-performing areas towards implementing agility successfully.

Table 3.32: Supply chain agility appraisement framework (Radfar et al., 2011)

Goal	1st level indices (capabilities/enablers) C_i	2nd level indices (attributes) C_{ij}	3rd level indices (criterions) C_{ijk}
Supply chain agility extent	Cost C_1	Sourcing cost C_{11}	Sourcing cost C_{111}
		Inventory cost C_{12}	Inventory cost C_{121}
		Costs incurred by lack of financial resources C_{13}	Costs incurred by lack of financial resources C_{131}
		Importing costs C_{14}	Cost of time spent in customers C_{141}
			Time spent for LC back account C_{142}
	Competency C_2	Supplier competency C_{21}	Number of suppliers C_{211}
			Number of components purchased per suppler C_{212}
		Service competency C_{22}	New product introduction C_{221}
			Quality of products or services C_{222}
			Time of new product development C_{223}
			Sales forecast C_{224}
		Customer competency C_{23}	Customer competency C_{231}
	Responsiveness and Quickness C_3	Supplier responsiveness and quickness C_{31}	Prolonged pre-closure plan C_{311}
			Supplier capacity C_{312}
		Service responsiveness and quickness C_{32}	Infrastructure deficit C_{321}
			Compatibility with existing bed level C_{322}
		Customer responsiveness and quickness C_{33}	Long term relationship with customers C_{331}
			Reliability of products C_{332}
	Flexibility C_4	Supplier flexibility C_{41}	Number of suppliers selected per component C_{411}
			Relationship with competitors C_{412}
		Service flexibility C_{42}	Number of products

			manufactured C_{421}
			Market penetration C_{422}
			Unscheduled jobs C_{423}
		Customer flexibility C_{43}	Delivery time C_{431}

Table 3.33: The scale of attribute weights

Scale	Grey weight
Very Low (VL)	[0.0, 0.1]
Low (L)	[0.1, 0.3]
Medium Low (ML)	[0.3, 0.4]
Medium (M)	[0.4, 0.5]
Medium High (MH)	[0.5, 0.6]
High (H)	[0.6, 0.9]
Very High (VH)	[0.9, 1.0]

Table 3.34: The scale of attribute ratings

Scale	Grey rating
Very Poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium Poor (MP)	[3, 4]
Medium (M)	[4, 5]
Medium Good (MG)	[5, 6]
Good (G)	[6, 9]
Very Good (VG)	[9, 10]

Table 3.42: Computation of GPII and corresponding agile criteria ranking

3rd level indices (criterions) C_{ijk}	$w'_{ijk} = (1,1) - w_{ijk}$	$GPII = w'_{ijk} \otimes U_{ijk}$	Grey possibility degree	Ranking order
C_{111}	[0.10, 0.40]	[0.90,4.00]	0.7249	6
C_{121}	[0.08, 0.34]	[0.48,3.06]	0.8888	13
C_{131}	[0.28, 0.46]	[2.184,4.416]	0.5797	3
C_{141}	[0.10, 0.40]	[0.520,2.640]	0.9727	16
C_{142}	[0.26, 0.48]	[1.092,2.496]	1.0000	17
C_{211}	[0.30, 0.48]	[2.520,4.704]	0.5107	1
C_{212}	[0.08, 0.34]	[0.448, 2.652]	0.9705	15
C_{221}	[0.22, 0.44]	[1.320, 3.960]	0.7073	5
C_{222}	[0.10, 0.40]	[0.600,3.600]	0.7954	10
C_{223}	[0.04, 0.22]	[0.288, 2.068]	1.0000	17
C_{224}	[0.10, 0.40]	[0.480, 2.480]	1.0000	17
C_{231}	[0.08, 0.34]	[0.400,2.040]	1.0000	17
C_{311}	[0.28, 0.46]	[1.680, 4.140]	0.6582	4
C_{312}	[0.08, 0.34]	[0.720, 3.40]	0.8225	11
C_{321}	[0.10, 0.4]	[0.600,3.600]	0.7954	10
C_{322}	[0.06, 0.28]	[0.504,2.744]	0.9504	14
C_{331}	[0.46, 0.56]	[1.932, 2.912]	0.8797	12
C_{332}	[0.16, 0.42]	[0.576, 1.932]	1.0000	17
C_{411}	[0.08, 0.34]	[0.48, 3.060]	0.8888	13
C_{412}	[0.08, 0.34]	[0.480, 3.060]	0.8888	13
C_{421}	[0.26, 0.48]	[2.340, 4.800]	0.5189	2
C_{422}	[0.10, 0.40]	[0.720, 3.760]	0.7669	9
C_{423}	[0.16, 0.42]	[1.056, 3.864]	0.7358	7
C_{431}	[0.10, 0.40]	[0.780, 3.840	0.7528	8
C_{432}	[0.04, 0.22]	[0.184, 1.232]	1.0000	17

3.3 Case Applications in Indian Perspective

3.3.1 Overview

Agility metrics are difficult to define, mainly due to the multidimensionality and vagueness of the concept of agility. In this work, a fuzzy logic, knowledge-based framework has been presented for the assessment of an enterprise's agility; in Indian perspectives. Apart from estimating overall agility appraisement index; the study has been extended to identify agile barriers (obstacles towards achieving agility). The proposed appraisement module has been case studied in Indian enterprises: (i) automobile part manufacturing industry and (ii) railway construction. Data obtained thereof, has been critically analyzed to reveal the current scenario of existing agile practices of the said enterprises and to seek for ill-performing areas which need future improvement.

Literature reveals that attempts have been made by pioneer researchers towards assessing agility. However, due to existence of imprecise incomplete evaluation information; it seems difficult to estimate an overall numeric score to represent the agility degree. Therefore, it requires subjective judgment collected from a highly experienced decision-making group to facilitate such an approximate estimation. Generalized trapezoidal fuzzy numbers set theory has been adapted here.

3.3.2 Background on Fuzzy Mathematics: Generalized Triangular Fuzzy Numbers

In order to deal with vagueness in human thought, Zadeh (1965) first introduced the fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non-statistical uncertainties. Moreover fuzzy set theory has been designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision inherent to decision making problems. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from (Zadeh, 1975; Buckley, 1985; Negi, 1989; Kaufmann and Gupta, 1991). The basic definitions and notations below will be used throughout this thesis until otherwise stated.

1 Definitions of fuzzy sets:

Definition 1: A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval $[0,1]$. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Kaufmann and Gupta, 1991).

Definition 2: A fuzzy set $\tilde{A}$ in a universe of discourse X is convex if and only if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min\left(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\right) \quad (3.81)$$

For all x_1, x_2 in X and all $\lambda \in [0,1]$, where $\min$ denotes the minimum operator (Klir and Yuan, 1995).

Definition 3: The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set $\tilde{A}$ in the universe of discourse X is called normalized when the height of $\tilde{A}$ is equal to 1 (Klir and Yuan, 1995).

2 Definitions of fuzzy numbers:

Definition 1: A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fig. 3.5 shows a fuzzy number $\tilde{n}$ in the universe of discourse X that conforms to this definition (Kaufmann and Gupta, 1991).

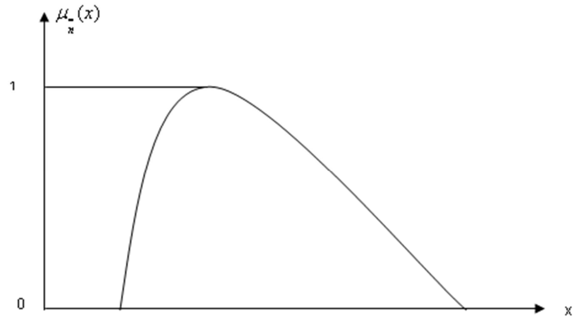

Fig. 3.5: A fuzzy number $\tilde{n}$

Definition 2: The α-cut of fuzzy number $\tilde{n}$ is defined as:

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\}, \quad (3.82)$$

Here $\alpha \in [0,1]$.

The symbol $\tilde{n}^{\alpha}$ represents a non-empty bounded interval contained in X, which can be denoted by $\tilde{n}^{\alpha} = [n_l^{\alpha}, n_u^{\alpha}]$, n_l^{α} and n_u^{α} are the lower and upper bounds of the closed interval, respectively (Kaufmann and Gupta, 1991; Zimmermann, 1991). For a fuzzy number $\tilde{n}$, if $n_l^{\alpha} > 0$ and $n_u^{\alpha} \leq 1$ for all $\alpha \in [0,1]$, then $\tilde{n}$ is called a standardized (normalized) positive fuzzy number (Negi, 1989).

Definition 3: Suppose, a positive triangular fuzzy number (PTFN) is $\tilde{A}$ and that can be defined as (a,b,c) shown in Fig. 3.6. The membership function $\mu_{\tilde{n}}(x)$ is defined as:

$$\mu_{\tilde{A}}(x)=\begin{cases}(x-a)/(b-a), & if\ a \le x \le b,\\ (c-x)/(c-b), & if\ b \le x \le c,\\ 0, & otherwise,\end{cases} \quad (3.83)$$

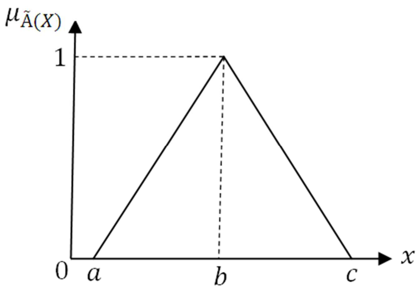

Fig. 3.6: A triangular fuzzy number $\tilde{A}$

Based on extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction Θ of any two triangular fuzzy numbers are also triangular fuzzy numbers; but the multiplication $\otimes$ of any two triangular fuzzy numbers is only approximate triangular fuzzy number (Zadeh, 1975). Let's have a two positive triangular fuzzy numbers, such as $\tilde{A}_1 = (a_{1,} b_1, c_1)$, and $\tilde{A}_2 = (a_2, b_2, c_2)$, and a positive real number $r = (r, r, r)$, some algebraic operations can be expressed as follows:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \quad (3.84)$$

$$\tilde{A}_1 \,\Theta\, \tilde{A}_2 = (a_1 - a_2, b_1 - b_2, c_1 - c_2), \quad (3.85)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a_1 a_2, b_1 b_2, c_1 c_2), \quad (3.86)$$

$$r \otimes \tilde{A}_1 = (ra_1, rb_1, rc_1), \quad (3.87)$$

$$\tilde{A}_1 \varnothing \tilde{A}_2 = (a_1/c_2, b_1/b_2, c_1/a_2), \quad (3.88)$$

The operations of $\vee$ (max) and $\wedge$ (min) are defined as:

$$\tilde{A}_1(\vee)\tilde{A}_2 = (a_1 \vee a_2, b_1 \vee b_2, c_1 \vee c_2), \quad (3.89)$$

$$\tilde{A}_1(\wedge)\tilde{A}_2 = (a_1 \wedge a_2, b_1 \wedge b_2, c_1 \wedge c_2), \quad (3.90)$$

Here, $r > 0$, and $a_1, b_1, c_1 > 0$,

Also the crisp value of triangular fuzzy number set $\tilde{A}_1$ can be determined by defuzzification which locates the Best Non-fuzzy Performance (BNP) value. Thus, the BNP values of fuzzy number are calculated by using the center of area (COA) method as follows: (Moeinzadeh and Hajfathaliha, 2010)

$$\text{BNP}_i = \frac{[(c-a)+(b-a)]}{3}+a, \qquad \forall_i, \tag{3.91}$$

Definition 4: A matrix $\tilde{\mathbf{D}}$ is called a fuzzy matrix if at least one element is a fuzzy number (Buckley, 1985).

3 Linguistic variables:

Definition 1: A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language, i.e., in terms of linguistic (Zadeh, 1975). The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Zimmermann, 1991). For example, 'weight' is a linguistic variable whose values are 'very low', 'low', 'medium', 'high', 'very high', etc. Fuzzy numbers can also represent these linguistic values.

4 DOS between two generalized fuzzy numbers

While assessing agility in fuzzy environment, agile criterions need to be ranked based on their performance rating. The ranking order thus obtained provides sufficient information of the current agile practices in relation to the said enterprise. As performance ratings are expressed in terms of fuzzy numbers; exploration of the concept of 'fuzzy numbers ranking' is indeed required towards obtaining criteria ranking order. As a result ill-performing criterions (agile barriers) can be identified easily. Generalized fuzzy numbers (triangular or trapezoidal fuzzy numbers) can be ranked based on individual utility values computed using the theory of 'maximizing set and minimizing set' (Kim and Park, 1990; Liou and Wang, 1992; Wang and Luo, 2009; Chou et al., 2011). The concept of fuzzy degree of similarity has already been proposed as an alternative mean towards ranking of Generalized Interval-Valued Fuzzy Numbers (GIVFNs) discussed in Section 3.1.2 of this chapter. Here, question arises, can't we use the concept of degree of similarity for obtaining ranking order of generalized fuzzy numbers. This may help in identifying agile barriers. After an exhaustive search in available literature, it has been found that the concept of DOS do exists for generalized fuzzy numbers also. A variety of concepts, computation methodology, and equation has been proposed by pioneers in order to compute DOS between two generalized fuzzy numbers. These have been presented below. These equations represent for computing DOS between two trapezoidal fuzzy numbers. These can also be utilized in case of triangular fuzzy numbers because a triangular fuzzy number can be easily approximated and represented by a trapezoidal fuzzy number.

In the case study in automobile sector, the theory behind fuzzy numbers ranking by 'maximizing set and minimizing set' has been explored towards indentifying agile barriers; while in the case study conducted in railway construction, DOS computation concepts by (Chen, 1996; Hsieh and Chen, 1999; Chen and Chen, 2003b; Yong et al., 2004) have been explored in order to identify various agile barriers.

For any two generalized trapezoidal fuzzy numbers,

$\tilde{\tilde{A}} = (a_1, a_2, a_3, a_4)$ and $\tilde{\tilde{B}} = (b_1, b_2, b_3, b_4)$

1. The similarity measure (Chen, 1996)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 1 - \frac{\sum_{i=1}^{4} |a_i - b_i|}{4} \tag{3.92}$$

2. In (Hsieh and Chen, 1999)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{1 + d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)} \tag{3.93}$$

Here $d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left| P\left(\tilde{\tilde{A}}\right) - P\left(\tilde{\tilde{B}}\right) \right|$

$$P\left(\tilde{\tilde{A}}\right) = \frac{a_1 + 2a_2 + 2a_3 + a_4}{6}, \; P\left(\tilde{\tilde{B}}\right) = \frac{b_1 + 2b_2 + 2b_3 + b_4}{6} \tag{3.94}$$

3. Simple centre of gravity method (Chen and Chen, 2003b)

The SCGM is based on the concept of medium curve (Subasic and Hirota, 1998). The SCGM method integrates the concepts of geometric distance and the COG distance of GFN's. If the GFN's are $\tilde{\tilde{A}} = \left(a_1, a_2, a_3, a_4; w_{\tilde{\tilde{A}}}\right)$ and $\tilde{\tilde{B}} = \left(b_1, b_2, b_3, b_4; w_{\tilde{\tilde{B}}}\right)$ and

$0 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$ and $0 \le b_1 \le b_2 \le b_3 \le b_4 \le 1$.

$COG\left(\tilde{\tilde{A}}\right) = \left(x^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{A}}}\right), COG\left(\tilde{\tilde{B}}\right) = \left(x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{B}}}\right)$ then

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 1 - \frac{\sum_{i=1}^{4} |a_i - b_i|}{4} \left(1 - \left| x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}} \right| \right)^{B\left(S_{\tilde{\tilde{A}}}, S_{\tilde{\tilde{B}}}\right)} \frac{\min\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)}{\max\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)} \tag{3.95}$$

Here,

$$y_A^* = \begin{cases} \dfrac{w_{\approx A}\left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2\right)}{6}, if\ a_1 \neq a_4, \\ \dfrac{w_{\approx A}}{2}, \quad if\ a_1 = a_4. \end{cases} \tag{3.96}$$

$$x_{\approx A}^* = \frac{y_{\approx A}^*(a_3 + a_2) + (a_4 + a_1)\left(w_{\approx A} - y_{\approx A}^*\right)}{2w_{\approx A}} \tag{3.97}$$

$$B\left(S_{\approx A}, S_{\approx B}\right) = \begin{cases} 1\ \ if\ S_A + S_B > 0 \\ 0\ \ if\ S_A + S_B = 0 \end{cases} \tag{3.98}$$

$$S_A = a_4 - a_1;\ S_B = b_4 - b_1 \tag{3.99}$$

4. The radius of gyration based similarity measure (Yong et al., 2004)

$$S\left(\approx A, \approx B\right) = 1 - \frac{\sum_{i=1}^{4}|a_i - b_i|}{4}\left(1 - \left|r_x^{\approx A} - r_x^{\approx B}\right|\right)^{B\left(S_{\approx A}, S_{\approx B}\right)} \frac{\min\left(r_y^{\approx A}, r_y^{\approx B}\right)}{\max\left(r_y^{\approx A}, r_y^{\approx B}\right)} \tag{3.100}$$

Here

$$r_x^{\approx A} = \sqrt{\frac{(I_x)_1 + (I_x)_2 + (I_x)_3}{\{(a_3 - a_2) + (a_4 - a_1)\}\frac{w_{\approx A}}{2}}} \tag{3.101}$$

$$r_y^{\approx A} = \sqrt{\frac{(I_y)_1 + (I_y)_2 + (I_y)_3}{\{(a_3 - a_2) + (a_4 - a_1)\}\frac{w_{\approx A}}{2}}} \tag{3.102}$$

$$(I_x)_1 = \frac{(a_2 - a_1)w_{\approx A}^3}{12} \tag{3.103}$$

$$(I_x)_2 = \frac{(a_3 - a_2)w_{\approx A}^3}{3} \tag{3.104}$$

$$(I_x)_3 = \frac{(a_4 - a_3)w_{\approx A}^3}{12} \tag{3.105}$$

$$(I_y)_1 = \frac{(a_2 - a_1)^3 w_{\approx A}}{4} + \frac{(a_2 - a_1)a_1^2 w_{\approx A}}{2} + \frac{2(a_2 - a_1)^2 a_1 w_{\approx A}}{3} \tag{3.106}$$

$$(I_y)_2 = \frac{(a_3 - a_2)^3 w_{\tilde{\tilde{A}}}}{3} + \frac{(a_3 - a_2) a_2^2 w_{\tilde{\tilde{A}}}}{1} + \frac{2(a_3 - a_2)^2 a_2 w_{\tilde{\tilde{A}}}}{1} \tag{3.107}$$

$$(I_y)_3 = \frac{(a_4 - a_3)^3 w_{\tilde{\tilde{A}}}}{12} + \frac{(a_4 - a_3) a_3^2 w_{\tilde{\tilde{A}}}}{2} + \frac{2(a_4 - a_3)^2 a_1 w_{\tilde{\tilde{A}}}}{3} \tag{3.108}$$

5. Similarity measure based on geometric mean averaging operator (Chen, 2006)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left[\sqrt[4]{\prod_{i=1}^{4}\left(2 - |a_i - b_i|\right)} - 1\right] \times \frac{\min\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)}{\max\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)} \tag{3.109}$$

Here $y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}$ are given by Eq. 3.97.

6. Fuzzy similarity measure proposed by (Sridevi and Nadarajan, 2009)

(Sridevi and Nadarajan, 2009) presented a new similarity measure based on fuzzy difference of distance of points of fuzzy numbers rather than geometric distances used by the existing methods. The membership function to measure the difference in distance of points of two GFN's is defined as

$$\mu_d(x) = \begin{cases} 1 - \dfrac{x}{d}, 0 \le x \le d \\ 0, Otherwise. \end{cases} \tag{3.200}$$

Here $0 < d \le 1$ and $x = |a_i - b_i|$. The degree of similarity of two GFN's $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ is defined as

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{4}\sum_{i=1}^{4} \mu_d(x)\left(1 - \left|x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}}\right|\right)^{B\left(S_{\tilde{\tilde{A}}}, S_{\tilde{\tilde{B}}}\right)} \frac{\min\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)}{\max\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)} \tag{3.201}$$

$B\left(S_{\tilde{\tilde{A}}}, S_{\tilde{\tilde{B}}}\right)$ is 0 or 1 according as COG point is considered or not and $x^*_{\tilde{\tilde{A}}}, x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}$ are given in Eqs. 3.96-3.97.

3.3.3 Appraisement Modelling and Procedural Framework Adapted

A fuzzy based performance appraisement module in agile manufacturing proposed in this work has been presented below. General Hierarchy Criteria (GHC) for evaluating overall organizational agility degree, adapted here has been shown in Table 3.43. It consists of three-level index system; which aims at achieving the target to evaluate overall appraisement index. 1st level lists out a number of agile capabilities/ enablers; 2nd level comprises of various agile attributes and the 3rd level illustrates agile criterions. Procedural steps for agility evaluation have been presented as follows:

1. Selection of linguistic variables towards assigning priority weights (of individual agile capabilities/attributes as well as criterions) and appropriateness rating (performance extent) corresponding to each 3rd level agile criterions.
2. Collection of expert opinion from a selected decision-making group (subjective judgment) in order to express the priority weight as well as appropriate rating against each of the evaluation indices.
3. Representing decision-makers' linguistic judgments using appropriate fuzzy numbers set.
4. Use of fuzzy operational rules towards estimating aggregated weight as well as aggregated rating (pulled opinion of the decision-makers) for each of the selection criterion.
5. Calculation of computed performance rating of 2nd level attributes and 1st level agile capabilities and finally overall agility performance index called Fuzzy Performance Index (FPI).

Appropriateness rating for each of the 2nd level attributes U_{ij} (rating of j_{th} attribute under i_{th} agile capability) has been computed as follows:

$$U_{ij} = \frac{\sum U_{ijk} \otimes w_{ijk}}{\sum w_{ij}k} \qquad (3.202)$$

In this expression (Eq. 3.202) U_{ijk} is denoted as the aggregated fuzzy appropriateness rating against k_{th} criterion under j_{th} agile attribute (at 2nd level) which is under i_{th} agile capability in the 1st level. w_{ijk} is the aggregated fuzzy weight against k_{th} agile criterion under j_{th} agile attribute (at 2nd level) which is under i_{th} agile capability in the 1st level.

Appropriateness rating for each of the 1st level capability U_i (rating of i_{th} agile capability) has been computed as follows:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \qquad (3.203)$$

In this expression (Eq. 3.203) U_{ij} is denoted as the computed fuzzy appropriateness rating against j_{th} agile attribute (at 2nd level) obtained using (Eq. 3.202) which is under i_{th} main criterion in the 1st level. w_{ij} is the aggregated fuzzy weight against j_{th} agile attribute (at 2nd level) which is under i_{th} main criterion in 1st level.

The *Fuzzy Performance Index (FPI)* (also called Fuzzy Agility Index) has been computed as:

$$U(FPI) = \frac{\sum U_i \otimes w_i}{\sum w_i} \tag{3.204}$$

In this expression (Eq. 3.204) U_i is denoted as the computed fuzzy appropriateness rating (obtained using Eq. 3.203) against i_{th} agile capability at 1st level. w_i is the aggregated fuzzy priority weight against i_{th} agile capability in 1st level.

6. Investigation for identifying ill-performing areas those seek for future improvement.

3.3.4 Agility Appraisement in Automotive Sector

The course towards conducting a cross-sectional study, which has been aimed at exploring the role various agile practices in Indian industries; the proposed appraisement module has been case studied in a famous automobile part manufacturing industry located at eastern part of India. In the primary stage, after extensive literature review and periodic discussions with the industries top management, an integrated hierarchy model towards agility assessment has been constructed and made for ready to implement. The model encompasses of various agile capabilities/ attributes as well as agile criterions. An evaluation team consisting of five experts has been deployed to assign priority weights (importance extent) against different agile capabilities/ attributes as well as agile criterions considered in the proposed appraisement model. A questionnaire has been formed and circulated among the decision-makers (experts) to provide the required detail. The decision-makers have been the employees of the said enterprise. 100 questionnaires have been circulated among them and out of 100, 80 respondents' opinions (80%) have been received. During data gathering it has been assured that the data would be strictly used for academic purpose only. Therefore, experts were requested to provide personal opinion (without any biasness) based on their experience. The outcome of this survey might be of enormous help to industries for improving productivity and profitability of companies; if implemented in reality.

Collected data has been explored to investigate application feasibility of the proposed appraisement platform. After critical investigation and scrutiny each decision-maker has been instructed to explore the linguistic scale (Table 3.44) towards assignment of priority weight and appropriateness rating against each evaluation indices. Tables 3.45-3.47 (furnished in Appendix) provide subjective judgment of the evaluation team members expressed through linguistic terms in relation to weight assignment against various agile capabilities-attributes as well as criterions. Appropriateness rating (subjective score as given by the 80 decision-makers) for 3rd level agile criterions has been furnished in (Appendix: Table 3.48). These linguistic expressions (human judgment) have been converted into appropriate generalized triangular fuzzy numbers as presented in Table 3.44. The method of *simple average* has been used to obtain aggregated priority weights of 3rd level agile criterions, 2nd level agile attributes as well as 1st level agile capabilities (Appendix: Tables 3.49-3.51). Similarly aggregated fuzzy appropriateness rating has been obtained for 3rd level criterions and shown in (Appendix: Table 3.49). Computed fuzzy performance ratings for 2nd level agile attributes and then 1st level agile capabilities have thus been obtained by using Eqs. 3.202-3.203 and tabulated in (Appendix: Tables 3.50-3.51). Finally, Eq. 3.204 has been used to obtain overall FPI. The FPI thus obtained as: ***U***= **(0.08, 0.68, 4.51)**.

The FPI may be compared with a predefined performance estimation scale set by the management to check the current performance practices for the suppliers'. Thus, ill-performing areas have been sorted out and in future said enterprise should think of feasible means towards improvement of overall agility degree.

The concept of '*Ranking of fuzzy numbers with maximizing set and minimizing set*' has been adapted here to identify ill-performing areas of agile performance. 3rd level agile criteria have been ranked based on their individual *Fuzzy Performance Importance Index* (FPII) [Lin et al., 2006]. It has been computed as follows:

$$FPII_k = \lfloor 1 - w_{ijk} \rfloor \otimes U_{ijk} \tag{3.205}$$

Here $FPII_k$ is denoted as the *Fuzzy Performance Importance Index* of k_{th} agile criterion; whose aggregated performance rating is U_{ijk} and aggregated priority weight w_{ijk} .

In this computation, three types of decision-makers risk bearing attitude $(\alpha = 0, \alpha = 0.5, \alpha = 1)$ *[risk averter, neutral and risk lover]* have been explored to estimate overall utility score u_T^{α} against each 3rd level agile criterions. The criterion with higher utility degree is assumed to have top ranking order. Thus, agile criterions have been ranked accordingly (Table 3.52).

This provides a snapshot of the existing agile scenario of the said organization. Table 3.52 provides necessary means for identifying agile barriers which require future improvement from managerial viewpoint. Proper action plans need to be taken by the top management in order to boost up overall organizational agility extent.

Table 3.43: The proposed agility appraisement model (3-level index system hierarchy)

Sl. No.	Level 1 indices (agile capabilities/enablers)	Level 2 indices (agile attributes)	Level 3 indices (agile criterions)
1.	Organization management agility C_1	Agility in institutional framework C_{11}	Existence of a well-defined system architecture to promote agility C_{111}
			Establishing a physically distributed manufacturing architecture precisely in a stable state C_{112}
			Ability to rapidly set up the entire organization adaptable to new method of operation C_{113}
			Frequency of enterprise modelling C_{114}
			Adaptability of best practices in other organizations by benchmarking C_{115}
			Application of business process reengineering (BPR) for reinventing and reengineering the organization C_{116}
			Good housekeeping practices C_{117}
		Team building agility C_{12}	Speed of the team building C_{121}
			Formation of team across company borders C_{122}
			Use of interdisciplinary teams by organizing themselves to take the advantages of market opportunities C_{123}
			Empowerment of personnel to resolve customer and process related problems C_{124}
		Production organizing agility C_{13}	Adoption of Concurrent Engineering (CE) C_{131}
			Identification of market for new products C_{132}
			Degree of innovation and new product development (NPD) techniques that calls for uniqueness and novelty in the product C_{133}
			Degree of automation applied to manufacturing C_{134}
			Degree of automation in inspection systems C_{135}
2.	Product Design Agility C_2	Product design flexibility C_{21}	Management's interest towards evolving new product models C_{211}
			Extent of inculcation of innovation into product design C_{212}
			Degree of Recycling orientation during product design C_{213}
			The serating degree of the product C_{214}
			Degree of standardization and commonality C_{215}
			Speed at which suppliers are being developed for new products C_{216}
			Similarity of the product structure C_{217}

Table 3.43 (Continued)

Sl. No.	Level 1 indices (agile capabilities/enablers)	Level 2 indices (agile attributes)	Level 3 indices (agile criterion)
			Preparedness of the management to invest on latest design techniques like RP and CAD/CAM C_{218}
			Products incorporated with modular design C_{219}
		Customer demand information agility C_{22}	Swiftness in obtaining demand information C_{221}
			Extent of customer satisfaction orientation C_{222}
			The proportion of information processing time in product period C_{223}
		Product Design speed C_{23}	Time for product development cycle time C_{231}
			Design selection that minimizes the no of parts C_{232}
			Design lead time C_{233}
3.	Processing manufacture agility C_3	Reconfigurability of manufacturing system C_{31}	Capability of packaging the integrated unit in a modular fashion C_{311}
			Supplement tool displacement C_{312}
			Displacement compatibility C_{313}
			Displacement of process variety C_{314}
			Design for manufacturing and assembly C_{315}
		Speed of manufacturing C_{32}	Period of both inter-lot and in-lot set up time C_{321}
			Speed of material handling systems C_{322}
			Leadership in the use of current technology C_{323}
			The overall period of product manufacture C_{324}
			The proportion of manufacturer period in products period C_{325}
		Manufacturing flexibility C_{33}	Flexible material handling equipment C_{331}
			The universal degree of equipment C_{332}
			The scalable degree of equipment C_{333}
			Flexibility of equipment C_{334}
4.	Partnership formation capability C_4	Inter-organization co-ordination C_{41}	Degree of enterprise integration C_{411}
			Degree of cooperation with other enterprise C_{412}
			Reliable network of suppliers C_{413}
			Adoption of SCM concepts for enhancing the outsourcing efficiency C_{414}
		Cross-border Collaboration C_{42}	Strategic relationship with customers C_{421}
			Speed of development of products jointly with other companies C_{422}
			Trust based relationship C_{423}

			Speed of partnership formation C_{424}
			Collaboration among partners C_{425}
			Formation of Virtual manufacturing enterprise(VME) C_{426}
5.	Integration of Information system C_5	Information management agility C_{51}	Interoperability and Networking C_{511}
			Ability to exchange information C_{512}
			Utilizing artificial intelligence(AI) with computer aided design C_{513}
			Correctness and accuracy of data C_{514}
			Maintenance information system C_{515}
			Companywide integration of information system C_{516}
			IT application to eliminate paper work C_{517}
			Adoption of multimedia technology C_{518}
		Speed of information C_{52}	Information and network utilization rate C_{521}
			Utilization of electronic data exchange system (EDI) C_{522}

Table 3.44: Linguistic scale towards estimating priority weight and assignment of performance rating

VH	H	M	L	VL
Very High	High	Middle	Low	Very Low
(0.75, 1, 1)	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0, 0.25)

Table 3.52: Ranking of agile criterions exploring the concept of ‘maximizing set and minimizing set’ in fuzzy set theory

3rd level indices (criterions) C_{ijk}	$w'_{ijk} = (1,1,1) - w_{ijk}$	FPII= $w'_{ijk} = [(1,1,1) - w_{ijk}] \otimes U_{ijk}$	$U_T^{\alpha=0}$	Rank	$U_T^{\alpha=0.5}$	Rank	$U_T^{\alpha=1}$	Rank
C_{111}	(0,0.15,0.4)	(0,0.11, 0.38)	0.0936	22	0.3253	28	0.5569	24
C_{112}	(0,0.25,0.5)	(0,0.17,0.47)	0.1348	6	0.5182	4	0.9015	1
C_{113}	(0,0.15, 0.4)	(0,0.1,0.35)	0.0883	29	0.3123	35	0.5363	33
C_{114}	(0,0.25,0.5)	(0,0.15, 0.41)	0.1234	13	0.5076	19	0.8917	17
C_{115}	(0,0.1,0.35)	(0,0.07, 0.3)	0.0623	45	0.2265	56	0.3907	56
C_{116}	(0,0.1,0.35)	(0,0.06, 0.3)	0.0600	48	0.2214	58	0.3828	58
C_{117}	(0,0.2,0.45)	(0,0.13,0.4)	0.1108	16	0.4055	22	0.7002	19
C_{121}	(0,0.25, 0.5)	(0,0.18,0.45)	0.1357	5	0.5158	6	0.8958	5
C_{122}	(0,0.15, 0.4)	(0,0.11,0.36)	0.0913	25	0.3175	32	0.5436	29
C_{123}	(0,0.15, 0.4)	(0,0.1,0.33)	0.0849	33	0.3033	40	0.5217	39
C_{124}	(0,0.25,0.5)	(0,0.16, 0.42)	0.1257	12	0.5095	16	0.8932	13
C_{131}	(0,0.15,0.4)	(0,0.1,0.34)	0.0839	35	0.3033	40	0.5227	38
C_{132}	(0,0.25,0.5)	(0,0.17, 0.43)	0.1299	10	0.5124	11	0.8949	7
C_{133}	(0,0.1,0.35)	(0,0.07, 0.31)	0.0653	42	0.2339	52	0.4025	52
C_{134}	(0,0.1,0.35)	(0,0.07, 0.3)	0.0626	44	0.2276	55	0.3927	55
C_{135}	(0,0.2,0.45)	(0,0.13, 0.39)	0.1076	18	0.3998	25	0.6920	22
C_{211}	(0,0.25, 0.5)	(0,0.18,0.45)	0.1366	4	0.5164	5	0.8963	4
C_{212}	(0,0.15, 0.4)	(0,0.11, 0.36)	0.0920	24	0.3187	31	0.5454	28
C_{213}	(0,0.15, 0.4)	(0,0.1,0.34)	0.0839	35	0.3033	40	0.5227	38
C_{214}	(0,0.15, 0.4)	(0,0.09, 0.33)	0.0835	36	0.3007	44	0.5178	44
C_{215}	(0,0.25, 0.5)	(0,0.17,0.42)	0.1299	10	0.5109	13	0.8918	16
C_{216}	(0,0.15, 0.4)	(0,0.1,0.35)	0.0893	27	0.3132	34	0.5372	32
C_{217}	(0,0.25, 0.5)	(0,0.17, 0.43)	0.1317	8	0.5128	9	0.8939	10
C_{218}	(0,0.1,0.35)	(0,0.07, 0.33)	0.0666	40	0.2404	48	0.4143	47
C_{219}	(0,0.1,0.35)	(0,0.07, 0.32)	0.0621	46	0.2289	54	0.3957	54
C_{221}	(0,0.15, 0.4)	(0,0.09, 0.34)	0.0835	36	0.3025	42	0.5215	40
C_{222}	(0,0.25, 0.5)	(0,0.16, 0.42)	0.1257	12	0.5097	15	0.8936	12
C_{223}	(0,0.15, 0.4)	(0,0.1,0.33)	0.0846	34	0.3025	42	0.5205	42
C_{231}	(0,0.25, 0.5)	(0,0.17, 0.44)	0.1321	7	0.5131	8	0.8941	9
C_{232}	(0,0.1,0.35)	(0,0.07, 0.31)	0.0641	43	0.2315	53	0.399	53
C_{233}	(0,0.1,0.35)	(0,0.07, 0.32)	0.0656	41	0.235	51	0.4044	51
C_{311}	(0,0.2,0.45)	(0,0.13, 0.39)	0.1088	17	0.4023	24	0.6958	21

Table 3.52 (Continued)								
3^{rd} level indices (criterions) C_{ijk}	$w'_{ijk} = (1,1,1) - w_{ijk}$	FPII= $w'_{ijk} = [(1,1,1) - w_{ijk}] \otimes U_{ijk}$	$U_T^{\alpha=0}$	Rank	$U_T^{\alpha=0.5}$	Rank	$U_T^{\alpha=1}$	Rank
C_{312}	(0,0.25,0.5)	(0,0.15, 0.42)	0.1234	13	0.5094	17	0.8954	6
C_{313}	(0,0.15, 0.4)	(0,0.09, 0.34)	0.0829	37	0.3003	45	0.5176	45
C_{314}	(0,0.15, 0.4)	(0,0.1,0.34)	0.0859	31	0.3059	37	0.5258	36
C_{315}	(0,0.15, 0.4)	(0,0.1,0.34)	0.0880	30	0.31	36	0.532	34
C_{321}	(0,0.25, 0.5)	(0,0.16, 0.43)	0.1285	11	0.5108	14	0.8931	14
C_{322}	(0,0.15, 0.4)	(0,0.1,0.35)	0.0890	28	0.3132	34	0.5373	31
C_{323}	(0,0.25, 0.5)	(0,0.17, 0.43)	0.1321	7	0.5127	10	0.8932	13
C_{324}	(0,0.1,0.35)	(0,0.07, 0.3)	0.0615	47	0.2256	57	0.3897	57
C_{325}	(0,0.1,0.35)	(0,0.06, 0.29)	0.0595	49	0.2198	59	0.3801	59
C_{331}	(0,0.2,0.45)	(0,0.13, 0.38)	0.1063	19	0.3981	26	0.6899	23
C_{332}	(0,0.25, 0.5)	(0,0.17, 0.44)	0.1317	8	0.5132	7	0.8948	8
C_{333}	(0,0.15, 0.4)	(0,0.10, 0.34)	0.0849	33	0.3047	39	0.5245	37
C_{334}	(0,0.25, 0.5)	(0,0.16, 0.42)	0.1257	12	0.5092	18	0.8927	15
C_{411}	(0,0.15, 0.4)	(0,0.10, 0.33)	0.0846	34	0.3028	41	0.521	41
C_{412}	(0,0.25, 0.5)	(0,0.15, 0.41)	0.1201	14	0.5071	20	0.8941	9
C_{413}	(0,0.1,0.35)	(0,0.06, 0.29)	0.0582	50	0.218	60	0.3778	60
C_{414}	(0,0.1,0.35)	(0,0.07, 0.30)	0.0615	47	0.2256	57	0.3897	57
C_{421}	(0,0.2,0.45)	(0,0.13, 0.40)	0.1108	16	0.4053	23	0.6997	20
C_{422}	(0,0.15, 0.4)	(0,0.09, 0.34)	0.0835	36	0.3014	43	0.5192	43
C_{423}	(0,0.25, 0.5)	(0,0.17, 0.43)	0.1303	9	0.5121	12	0.8938	11
C_{424}	(0,0.15, 0.4)	(0,0.10, 0.34)	0.0856	32	0.3058	38	0.5260	35
C_{425}	(0,0.25, 0.5)	(0,0.19, 0.47)	0.1434	2	0.5214	1	0.8994	2
C_{426}	(0,0.1,0.35)	(0,0.07, 0.33)	0.0668	39	0.24	49	0.4133	49
C_{511}	(0,0.1,0.35)	(0,0.08, 0.34)	0.0686	38	0.2444	46	0.4203	46
C_{512}	(0,0.2,0.45)	(0,0.15, 0.42)	0.1198	15	0.4188	21	0.7178	18
C_{513}	(0,0.25, 0.5)	(0,0.19, 0.46)	0.1438	1	0.5196	2	0.8954	6
C_{514}	(0,0.15, 0.4)	(0,0.11, 0.36)	0.0923	23	0.3192	30	0.5461	27
C_{515}	(0,0.15, 0.4)	(0,0.10, 0.35)	0.0897	26	0.3135	33	0.5374	30
C_{516}	(0,0.1,0.35)	(0,0.07,0.32)	0.0656	41	0.2352	50	0.4048	50
C_{517}	(0,0.1,0.35)	(0,0.08,0.32)	0.0686	38	0.2411	47	0.4137	48
C_{518}	(0,0.15, 0.4)	(0,0.11,0.36)	0.0946	21	0.3236	29	0.5526	26
C_{521}	(0,0.25, 0.5)	(0,0.19,0.46)	0.1413	3	0.5188	3	0.8964	3
C_{522}	(0,0.15, 0.4)	(0,0.11,0.37)	0.0959	20	0.326	27	0.5561	25

3.3.5 Agility Appraisement in Railway Construction

In this part of work, agility evaluation has been attempted in a case study of a railway construction Industry at eastern part of India. The ideology for data collection has been same as reported in the previous case study of automobile sector. An evaluation team consisting of five experts has been deployed to assign priority weights (importance extent) against different agile capabilities as well as agile attributes considered in the proposed appraisement model. A questionnaire has been formed and circulated among the decision-makers (experts) to provide the required detail. The decision-makers have been the employees of the said enterprise. As described in Section 3.3.4; the same agility appraisement platform (Table 3.43) has been explored here. For simplicity in analysis and quick data collection, the appraisement platform up to 2nd level (considering agile capabilities as well as attributes) has been considered in this work.

Collected data has been explored to investigate application feasibility of the proposed appraisement platform. After critical investigation and scrutiny each decision-maker has been instructed to explore the linguistic scale (Table 3.44; Section 3.3.4) towards assignment of priority weight and appropriateness rating against each evaluation indices. Tables 3.46-3.47 (furnished in Appendix) provide subjective judgment of the evaluation team members (same as previous case study) expressed through linguistic terms in relation to weight assignment against various agile capabilities as well as attributes. Appropriateness rating (subjective score as given by the 20 decision-makers: employees of the organization) for 2nd level agile attributes has been furnished in (Appendix: Table 3.53). These linguistic expressions (human judgment) have been converted into appropriate generalized triangular fuzzy numbers as presented in Table 3.44 of Section 3.3.4. The method of *simple average* has been used to obtain aggregated priority weights of 2nd level agile attributes, as well as 1st level agile capabilities (Appendix: Tables 3.54-3.55). Similarly aggregated fuzzy appropriateness rating has been obtained for 2nd level attributes and then computed for 1st level agile capabilities and tabulated in (Appendix: Tables 3.54-3.55). Finally, overall FPI has been computed. The FPI thus obtained as: ***U***= **(0.0909, 0.5081, 2.20839)**.

Computed FPI for railway construction industry has been compared with that of the automobile sector. Comparison (Chou et al., 2011) results are presented below.

$\boldsymbol{FPI_A}$= **(0.08, 0.68, 4.51)**

$\boldsymbol{FPI_R}$= **(0.0909, 0.5081, 2.20839)**

[A: Automobile sector, R: Railway construction]

FPI	$U_T^{\alpha=0}$	$U_T^{\alpha=0.5}$	$U_T^{\alpha=1}$	Ranking order
FPI_A	0.0596	0.4139	0.76816	1
FPI_B	0.0455	0.1488	0.252011	2

This indicates that automobile sector is more agile as compared to the railway construction.

As an extension of the present work; attempts have been made to identify agile barriers of the said organization. Firstly, the concept of fuzzy numbers ranking by 'maximizing set as well as minimizing set' has been utilized towards identifying ill-performing areas (Table 3.56). Secondly, the concept of '*Degree of similarity between two fuzzy numbers*' (Chen, 1996; Hsieh and Chen, 1999; Chen and Chen, 2003b; Yong et al., 2004) has been adapted here to indentify ill-performing areas of agile performance. In this computation, 2nd level agile attributes have been ranked based on their individual *Fuzzy Performance Importance Index* (FPII) [Lin et al., 2006a, b]. It has been computed as follows:

$$FPII_j = [1 - w_{ij}] \otimes U_{ij} \tag{3.206}$$

Here $FPII_j$ is denoted as the *Fuzzy Performance Importance Index* of j_{th} agile attribute; whose aggregated performance rating is U_{ij} and aggregated priority weight w_{ij}.

The degree of similarity between FPII of individual agile attributes with respect to the *ideal FPII* has been computed. Higher value to DOS corresponds to a higher ranking order. Thus, agile attributes have been ranked accordingly (Table 3.57).

3.3.6 Managerial Implications

In the foregoing study a fuzzy-based performance appraisement module has been proposed and implemented in real case studies to evaluate extent of successful performances of current agile practices of the said industry. Apart from estimating an overall agility degree, the study has been illustrated to identify possibilities as well as necessities for future improvement towards identifying ill-performing agile criterions. 'Agility' as a whole, is a concept of introducing speediness, responsiveness into the existing system, associated supply chain. Achieving 'agility', an industry can gain competitive advantage in the global market. It is indeed difficult to assess agility quantitatively since most of the agile capabilities-attributes as well as criterions are subjective in nature; incompleteness, imprecision and vagueness arises in the decision-making process. In order to tackle such types of inconsistency; fuzzy expert system has been proposed here to deal with decision-makers' subjective judgment towards performance estimation of various agile indices. The proposed decision-support model has been found fruitful in aggregating performance of multiple agile indices into an equivalent single performance appropriateness index. The industries may adopt such an appraisement policy to examine the present agility level, identify ill-performing areas (agile barriers) and seek for feasible means towards overcoming existing agile barriers.

3.3.7 Concluding Remarks

The contribution of this research has been furnished below.

1. Development of fuzzy-based integrated agility appraisement module. Industries/ enterprises can utilize this appraisement module as a test kit to assess and improve agility degree.
2. Estimation of overall agility index; identification of agile barriers.
3. Based on estimated overall agility index; different agile industries can be ranked accordingly.

The limitation as well as future research directions of the aforesaid research have been described below.

1. Subjective criteria weight as well as appropriateness rating has been expressed here in terms of triangular fuzzy number. The fuzzy number and to which membership function (MF) the evaluation result would be the most accurate; has not been checked.
2. Apart from triangular fuzzy numbers; generalized trapezoidal fuzzy number, even Interval-Valued fuzzy numbers (IVFNs) may be explored to express decision-makers subjective opinion into appropriate fuzzy numbers, thereby, increasing level of accuracy of prediction.
3. After identifying agile barriers, industry should think possible opportunities (in logical way) to boost up its agility degree. After confirming various opportunities to enrich agility; these opportunities must be practically implemented and increment in agility degree (after implementation) need to be quantified to check whether these opportunities are really working satisfactorily or not.

On implementing necessary tools for future improvement; after a consideration time span, the existing enterprise agility level must be evaluated to validate whether agility level is enhanced or not in comparison to the past.

Table 3.56: Ranking of agile attributes based on the concept of 'overall utility degree'

2nd level attributes, C_{ij}	$w'_{ij} = (1,1,1) - w_{ij}$	$FPII = w'_{ij} \otimes U_{ij}$	$U_T^{\alpha} = 0$	Rank	$U_T^{\alpha} = 1$	Rank	$U_T^{\alpha} = 1$	Rank
C_{11}	(0, 0.15,0.4)	(0,0.0356,0.195)	0.034214	13	0.12011	13	0.20601	13
C_{12}	(0,0.25,0.5)	(0,0.0781,0.283)	0.069367	8	0.20615	9	0.34294	9
C_{13}	(0,0.15,0.4)	(0,0.0844,0.315)	0.074094	7	0.23001	7	0.38594	7
C_{21}	(0,0.25,0.5)	(0,0.1094,0.348)	0.092008	3	0.27457	4	0.45713	4
C_{22}	(0,0.1,0.35)	(0,0.0550,0.280)	0.050926	10	0.17694	10	0.30295	10
C_{23}	(0,0.1,0.35)	(0,0.0700,0.315)	0.063063	9	0.21232	8	0.36159	8
C_{31}	(0,0.2,0.45)	(0,0.1225,0.373)	0.100823	2	0.30653	2	0.51224	2
C_{32}	(0,0.25,0.5)	(0,0.2031,0.475)	0.147593	1	0.46896	1	0.79033	1
C_{33}	(0,0.15,0.4)	(0,0.0994,0.365)	0.085027	5	0.27733	3	0.46963	3
C_{41}	(0,0.15,0.4)	(0,0.0863,0.325)	0.075492	6	0.23757	6	0.39965	6
C_{42}	(0,0.1,0.35)	(0,0.0363,0.214)	0.034772	12	0.12774	12	0.22070	12
C_{51}	(0,0.1,0.35)	(0,0.0488,0.251)	0.045667	11	0.15999	11	0.27430	11
C_{52}	(0,0.25,0.5)	(0,0.1063,0.335)	0.089852	4	0.26741	5	0.44496	5

Table 3.57: Ranking of agile attributes based on the concept of 'fuzzy degree of similarity'

2nd level attributes, C_{ij}	DOS (Chen, 1996)	Ranking order	DOS (Hsieh and Chen, 1999)	Ranking order	DOS (Chen and Chen, 2003b)	Ranking order	DOS (Yong et al., 2004)	Ranking order
C_{11}	0.8881	13	0.8633	12	0.7556	13	0.3036	13
C_{12}	0.9203	9	0.8964	8	0.8225	9	0.4682	9
C_{13}	0.9303	7	0.9043	6	0.8439	7	0.5267	7
C_{21}	0.9438	4	0.9222	3	0.8730	4	0.6064	4
C_{22}	0.9142	10	0.8840	9	0.8097	10	0.4486	10
C_{23}	0.9267	8	0.8965	7	0.8362	8	0.5138	8
C_{31}	0.9539	2	0.9337	2	0.8953	2	0.6693	2
C_{32}	1.0000	1	1.0000	1	1.0000	1	1.0000	1
C_{33}	0.9466	3	0.9195	4	0.8791	3	0.6227	3
C_{41}	0.9333	6	0.9067	5	0.8503	6	0.5443	6
C_{42}	0.8931	12	0.8660	11	0.7659	12	0.3362	12
C_{51}	0.9072	11	0.8779	10	0.7949	11	0.4103	11
C_{52}	0.9414	5	0.9195	4	0.8679	5	0.5921	5

CHAPTER 4

ORGANIZATIONAL AGILITY, BENCHMARKING OF AGILE SYSTEMS AND ANALYSIS OF RISK IN DECISION-MAKING

4.1 Appraisement of Organizational Agility

4.1.1 Overview

An agile enterprise is a fast moving, adaptable and robust business. It is capable of rapid adaptation in response to unexpected and unpredicted changes and events, market opportunities, and customer requirements. Such a business is founded on processes and structures that facilitate speed, adaptation and robustness and that deliver a coordinated enterprise that is capable of achieving competitive performance in a highly dynamic and unpredictable business environment that is unsuited to current enterprise practices.

Agility metrics seem difficult to properly define in general, mainly due to the multidimensionality and vagueness of the concept of agility itself; the extent of agility is nothing but a qualitative estimation. To address this issue, in this work, a systematic procedural framework has been proposed as a candidate solution for the assessment of organizational agility. Given an enterprise, in order to estimate its overall agility degree, a set of quantitatively defined agility enabler-attribute and criteria have been considered. The necessary expertise used to determine and measure individual agility parameters has been represented via fuzzy logic terminology that allows for human-like knowledge representation and reasoning. Using the concept of generalized trapezoidal fuzzy numbers set and their operational rules, an overall Fuzzy Agility Index (FAI) has been computed. Agile criterions have been ranked in accordance with their degree of performance towards contributing organizational agility. Poorly performing criterions (agile barriers) have been identified as well. An example has demonstrated the feasibility and applicability of the proposed approach.

4.1.2 Agile Enterprise

Agility is a concept that incorporates the ideas of flexibility, balance, adaptability, and coordination under a common base. In a business context, agility typically refers to the ability of an organization to rapidly adapt to market and environmental changes in productive and cost-effective ways. The agile enterprise is an extension of this concept, referring to an organization that utilizes key principles of complex adaptive systems and complexity science to achieve success (Tsourveloudis and Valavanis, 2002).

An agile enterprise strives to make change a routine part of organizational life to reduce or eliminate the organizational trauma that paralyzes many businesses attempting to adapt to new markets and environments (Hamel and Valikangas, 2003). Because change is perpetual, the agile enterprise is able to nimbly adjust to and take advantage of emerging opportunities. The agile enterprise views itself as an integral component of a larger system whose activities produce a ripple effect of change both within the enterprise itself and the broader system (Holbrook, 2003).

One type of enterprise architecture that supports agility is a non-hierarchical organization without a single point of control (Stacey et al., 2000). Individuals function autonomously, constantly interacting with each other to define the work that needs to be done. Roles and responsibilities are not predetermined but rather emerge from individuals' self-organizing activities and are constantly in flux. Similarly, projects are generated everywhere in the enterprise, sometimes even from outside affiliates. Key decisions are made collaboratively, on the spot, and on the fly. Because of this, knowledge, power, and intelligence are spread through the enterprise, making it uniquely capable of quickly recovering and adapting to the loss of any key enterprise component.

In business, projects can be complex with uncertain outcomes and goals can change over time. Traditionally these issues were dealt with by planning experts that would attempt to pre-determine every possible detail prior to implementation; however, in many situations, even the most carefully thought out projects will be impossibly difficult to manage. Agile techniques, originating from the software development community, represent an alternative approach to the classic prescriptive planning approaches to management. The main focus of agile methods is to address the issues of complexity, uncertainty, and dynamic goals, by making planning and execution work in parallel rather than in sequence to eliminate unnecessary planning activity, and the resulting unnecessary work.

Agile methods integrate planning with execution allowing an organization to 'search' for an optimal ordering of work tasks and to adjust to changing requirements. The major causes of chaos on a project include incomplete understanding of project components, incomplete understanding of component interactions and changing requirements. Sometimes, requirements change as a greater understanding of the project components unfolds over time. Requirements also change due to changing needs and wants of the stakeholders. The agile approach allows a team or organization to implement successful projects quickly by only focusing on a small set of details in any change iteration. This is in contrast to non-agile approaches. Interactions, self-organizing, co-evolution, and the edge of chaos are concepts borrowed from complexity science that can help define some of the processes that take place within an agile enterprise.

In short, an agile enterprise is a fast moving, flexible and robust firm capable of rapid response to unexpected challenges, events, and opportunities. Built on policies and processes that facilitate speed and change, it aims to achieve continuous competitive advantage in serving its customers. Agile enterprises use diffused authority and flat organizational structure to speed up information flows among different departments, and develop close, trust-based relationships with their customers and suppliers. Researchers in the enterprise agility group are focusing on improving an organization's ability to drive change, to sense and respond readily to change, and to learn from that change in today's business environment of unprecedented turbulence (Gunasekaran, 1999; Tsourveloudis and Valavanis, 2002; Sherehiy et al., 2007; Erande and Verma, 2008; Mansouri et al., 2011).

4.1.3 Background and Problem Statement

Ever-changing is one of firms' major characteristics in this new competitive era. Agile manufacturing (AM) has been increasingly viewed as a winning strategy (Breu, 2001; Barrand, 2006). AM is an integration of technologies, people, facilities, information systems and business processes (Chandna (Kharbanda), 2008). Measuring agility is important to identify the organizational effectiveness and identifies less agile areas in the enterprise and thus it can plan for improvements. Moreover, measurement of agility gives enterprise an indication for its competitiveness and readiness for changes in the market so that the enterprise can stay competitive in the market. Measuring agility should focus on specific agility types from which overall agility measures will be derived from (Nasr et al., 2011; Yaghoubi et al., 2011).

Apart from selecting agile criteria and developing conceptual framework (Kassim and Zain, 2004; Ramesh and Devadasan, 2007; Sherehiy et al., 2007; Banihashemi and Sarani, 2012) to model for organizational agility in various sectors; the degree of agility that the agile system possess has been viewed as a major area of concern. Extent of agility computation is seemed to be very challenging due to involvement of uncertain, imprecise or vague estimation of the subjective agile criteria. In most of the cases, decision-makers have to undergo subjective judgments, in appropriate linguistic terminology, to put ratings against subjective (qualitative) agile criteria. The research outcome reported by previous investigators focused on immense popularity of fuzzy set theory in dealing with agility appraisement systems.

Jain and Benyoucef (2008) presented an approach to model agility and introduced *Dynamic Agility Index* through fuzzy intelligent agents. Yang and Li (2002) suggested the establishment of an agility evaluation index system of mass customized (MC) product manufacturing based on the characteristics of MC product manufacturing and the requirements of agility manufacturing. Tsourveloudis and Valavanis (2002) proposed a knowledge based framework for the measurement and assessment of manufacturing agility. Shih and Lin (2002) proposed a fuzzy based approach for agility analysis for a manufacturing firm. Lin et al. (2006a, b) developed a fuzzy agility index (FAI) based on agility providers using fuzzy logic. Tsai et al. (2008) used fuzzy-logic QFD approach in order to align agile drivers, capabilities and providers to achieve agility. Wang (2009) proposed a suitable agile system for implementing MC. The author highlighted a MC manufacturing agility evaluation approach based on concepts of TOPSIS through analyzing the agility of organization management, product design, processing manufacture, partnership formation capability and integration of information system. (Seyedhoseini et al.; 2010) developed an approach based on Adaptive Neuro Fuzzy Inference System (ANFIS) for measurement of agility in Supply Chain. Vinodh et al. (2010a, b) and Vinodh et al. (2011) attempted to assess the agility level of an organization using a multi-grade fuzzy approach.

Shahrabi (2011) proposed the agility of the organization and its relationship Grason model in order to efficiently implement the fuzzy logic based on strength and flexibility and change in cash and the growing move toward agility. Kaveh et al. (2011) proposed a hybrid approach in order to measure the relative efficiency of agility in supply chains. Yauch (2011) constructed a quantitative, objective metric for agility performance that assessed agility as a performance outcome, capturing both organizational success and environmental turbulence, and applicable to manufacturing organizations of all types. Tseng and Lin (2011) suggested an agility development method for dealing with the interface and alignment issues among the agility drivers, capabilities and providers using the QFD relationship matrix and fuzzy logic.

In this context, the present study aims to develop a group decision-making procedural hierarchy based on generalized trapezoidal fuzzy number sets for agility index appraisement for an enterprise. Detailed methodology of the proposed approach has been illustrated while implementing in a case study to ensure considerable extent of reliability in such an evaluation process. The purpose of this research aims to construct a quantitative, objective metric for agility performance that assesses agility as a performance outcome, capturing both organizational success and environmental turbulence, and applicable to manufacturing organizations of all types.

4.1.4 Procedural Framework: Case Study

Agility evaluation has been attempted by the procedural framework as described as follows. A model (Table 4.1) has been adapted for organizational agility appraisement and implemented as a case study in an Indian famous automobile part manufacturing industry at eastern part of

India. The results obtained thereof have been analyzed and interpreted from managerial viewpoint. This has been illustrated as follows.

1 Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of agile attributes

The linguistic terms have been used to assess the performance ratings and priority weights of agile providers (as well as attributes) since it is difficult for the decision-makers to determine the numeric score of a subjective attribute. In order to assess the performance rating of various agile attributes, the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used in the present work. In order to assess the importance weights (priority degree) of agile providers as well as attributes, the following linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized. The linguistic variables (Table 4.2) have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation.

2 Measurement of performance ratings and importance weights of agile attributes using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of agile attributes has been accepted by the decision-makers (DMs), the decision-makers have been instructed to use aforesaid linguistic scales to assign importance weights for agile providers and agile attributes (Appendix: Tables 4.3- 4.4) as well as to assess the performance rating against each agile attributes (Appendix: Table 4.5).

3 Approximation of the linguistic terms by fuzzy numbers

Using the concept of fuzzy logic reasoning, the linguistic variables have been approximated by generalized trapezoidal fuzzy numbers. Next, the aggregated decision-making cum evaluation matrix, which corresponds to the aggregated fuzzy rating against each agile attribute (Grade III) with corresponding aggregated fuzzy weight, has been constructed and shown in (Appendix: Table 4.6). Also aggregated fuzzy priority weights for agile providers (Grade II) have been furnished in (Appendix: Table 4.7). Decision-makers pulled opinion (average) has been considered for evaluating aggregated fuzzy rating as well as priority weights.

4 Determination of FAI

FAI represents overall enterprise level agility (Lin et al., 2006a, b) and termed as *fuzzy agility index*. The fuzzy agility index has been calculated at the attribute level and then extended to enabler (provider) level. Fuzzy index at the attribute level encompasses several agile attributes. The fuzzy index of Grade-II agile provider can be calculated using the formula:

$$U_i = \frac{\sum (w_{ij} \otimes U_{ij})}{\sum w_{ij}} \tag{4.1}$$

Here U_{ij} represents performance rating of j^{th} attribute C_{ij} under i^{th} agile criteria C_i and w_{ij} represent fuzzy weight for priority importance corresponding to the said agile attribute. Overall Fuzzy Agility Index (FAI) can be calculated as:

$$U(FAI) = \frac{\sum w_i \otimes U_i}{\sum w_i} \tag{4.2}$$

Here U_i represents performance rating of i^{th} agile provider C_i and w_i is the corresponding weight.

Organizational Agility $(U) = \dfrac{\sum_{i=1}^{n} (w_i \otimes U_i)}{\sum_{i=1}^{n} w_i} = \dfrac{(3.51, 3.96, 4.90, 5.17; 0.8)}{(5.06, 5.31, 5.74, 5.86; 0.8)} = (0.69, 0.74, 0.85, 0.88; 0.8)$

After evaluating FAI, simultaneously it is also felt indeed necessary to identify and analyze the obstacles (called agile barriers) for agility improvement. Therefore, in this study, the proposed fuzzy agility appraisement system has been extended to investigate on the weakly-performing areas for improvement using the concept of ranking generalized trapezoidal fuzzy numbers. The purpose is to rank various agile providers as well as attributes according to their degree of performance. By this procedure poorly performing areas can be identified as well.

In this study, the concept of ranking fuzzy numbers based on 'maximizing set and minimizing set' (described in Section 3.1.1.5 of Chapter 3) has been explored to identify various agile barriers (both at Grade II and Grade III). The ranking score corresponding to various agile attributes (Grade III) as well as agile providers (Grade II) have been computed (shown in Table

4.8 and Table 4.9 respectively) based on their corresponding fuzzy performance rating. Three types of decision-makers risk bearing attitude $(k = 0.5,1,2)$ (i.e. conservative, fair and adventurous) have been assessed in computing ranking score of various agile providers and agile attributes. This helps in identifying weak agile elements which need further improvement.

4.1.5 Concluding Remarks

The advantages of the proposed model can help in the following aspects:

1. Quantitative assessment and precise estimation of overall agility degree.
2. Identification of agile barriers and their priority importance.
3. Benchmarking of various agile enterprises based on overall agility degree.
4. Investigation on week areas which require future improvement to reach the targeted agility level that the superiors possess.

Table 4.1: Organizational agility appraisement model (adapted from Shih and Lin, 2002)

Grade I	Grade II (Agile Provider), C_i	Grade III (Agile Attributes), C_{ij}
Organizational Agility, C	Human knowledge and skills, C_1	Multi-skilled and flexible employees, C_{11}
		Up gradation of workforce skill, C_{12}
	Customization, C_2	New product Introduction, C_{21}
		Responsiveness to change in market
		Products with substantial value-addition, C_{23}
		First-time right design, C_{24}
	Partnership, C_3	Strategic relationship with customers, C_{31}
		Trust-based relationship with suppliers, C_{32}
	Technology, C_4	Technology awareness, C_{41}
		Skill and knowledge enhancing, C_{42}
	Integration and competence, C_5	Concurrent execution of activities, C_{51}
		Information technology and communication
	Team work, C_6	Empowerment and decentralized decision
		Cross functional team, C_{62}
		Culture of change, C_{63}

Table 4.2: Definitions of linguistic variables for criteria ratings
(A-9 member generalized trapezoidal fuzzy numbers set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	(0, 0, 0, 0; 0.8)
Very Poor (VP)	Very Low (VL)	(0, 0, 0.02, 0.07; 0.8)
Poor (P)	Low (L)	(0.04, 0.10, 0.18, 0.23; 0.8)
Medium Poor (MP)	Medium Low (ML)	(0.17, 0.22, 0.36, 0.42; 0.8)
Medium (M)	Medium (M)	(0.32, 0.41, 0.58, 0.65; 0.8)
Medium Good (MG)	Medium High (MH)	(0.58, 0.63, 0.80, 0.86; 0.8)
Good (G)	High (H)	(0.72, 0.78, 0.92, 0.97; 0.8)
Very Good (VG)	Very High (VH)	(0.93, 0.98, 1, 1; 0.8)
Absolutely Good (AG)	Absolutely High (AH)	(1, 1, 1, 1; 0.8)

Table 4.8: Ranking score of agile attributes (Grade III)

C_{ij}	U_{ij}	Total utility score $[U_T(i)]$ or Ranking score		
		k=1 (Fair DM)	k=2 (Adventurous DM)	k=0.5 (Conservative DM)
C_{11}	(0.63,0.69,0.80,0.84; 0.8)	0.6870	0.6093	1.4378
C_{12}	(0.55,0.61,0.77,0.83; 0.8)	0.5859	0.5481	1.2917
C_{21}	(0.69,0.74,0.85,0.89; 0.8)	0.7912	0.6883	1.5839
C_{22}	(0.42,0.50,0.66,0.73; 0.8)	0.3738	0.4053	0.9954
C_{23}	(0.95,0.98,1.00,1.00; 0.8)	1.1987	*undefined*	2.3294
C_{24}	(0.72,0.76,0.88,0.92; 0.8)	0.8467	0.7313	1.6597
C_{31}	(0.91,0.94,0.98,0.99; 0.8)	1.1366	0.9520	2.1716
C_{32}	(0.74,0.79,0.91,0.95; 0.8)	0.9013	0.7898	1.7415
C_{41}	(0.69,0.74,0.85,0.89; 0.8)	0.7912	0.6883	1.5839
C_{42}	(0.63,0.69,0.80,0.84; 0.8)	0.6870	0.6093	1.4378
C_{51}	(0.84,0.88,0.96,0.98; 0.8)	1.0470	0.8967	1.9829
C_{52}	(0.55,0.61,0.77,0.83; 0.8)	0.5859	0.5481	1.2917
C_{61}	(0.89,0.93,0.98,0.99; 0.8)	1.1179	0.9519	2.1265
C_{62}	(0.67,0.74,0.85,0.90; 0.8)	0.7838	0.7012	1.5760
C_{63}	(0.65,0.70,0.86,0.91; 0.8)	0.7638	0.6845	1.5368

Table 4.9: Ranking score of agile providers (Grade II)

C_i	U_i	Total utility score $[U_T(i)]$ or Ranking score		
		k=1(Fair DM)	k=2 (Adventurous DM)	k=0.5 (Conservative DM)
C_1	(0.59,0.65,0.78,0.83; 0.8)	0.4443	0.5458	0.4482
C_2	(0.65,0.71,0.83,0.87; 0.8)	0.6012	0.6450	0.5365
C_3	(0.81,0.86,0.94,0.96; 0.8)	0.9947	0.9258	0.7669
C_4	(0.66,0.72,0.82,0.81; 0.8)	0.5709	0.5857	0.5266
C_5	(0.70,0.74,0.86,0.90; 0.8)	0.7012	0.7054	0.5897
C_6	(0.74,0.79,0.89,0.93; 0.8)	0.8159	0.7911	0.6568

4.2 Grey Theory and Fuzzy-TOPSIS Based Decision-Making Approaches for Agility Evaluation and Benchmarking of Mass-Customization Systems

4.2.1 Overview

The main purpose of the present study is to develop an agility evaluation module to determine the most suitable agile system for implementing mass customization (MC) strategies. Evaluating the alternatives and comparing across them, the best practices of the efficient organization can be identified and transferred to different organizations.

Grey relation approach is a simple mathematical technique useful in situations where the information is not known precisely. Grey relation approach has been applied to measure the agility of various organizations based on agile entities and accordingly the organizations are ranked. The ranking so obtained is compared with the ranking obtained by a popular Multi-Attribute Decision Making (MADM) process known as Fuzzy-TOPSIS (technique for order preference by similarity to ideal solution) to test the robustness of the proposed method (Chen, 2000; Deng et al., 2000). It is to be noted that grey theory considers the condition of the fuzziness and can deal flexibly with the fuzziness situation.

It is demonstrated that the grey approach is an appropriate method for solving MADM problems in an uncertain situation with less computational efforts. The alternatives can easily be benchmarked and the best agile system can be selected. As the ranking obtained through grey relation approach closely agree with the ranking found from Fuzzy-TOPSIS method, the robustness of the proposed approach is validated. Both the method leads to choose a suitable agile system related to mass customization.

Since the approach is quite generic one, managers can adopt the proposed method for decision making purpose when information on the system is not completely known or partially known. The benchmarking of alternatives (organizations) helps to make a comparison among them and transfer the best practices to achieve agility so that the concept of mass customization can be implemented. The inefficient organizations can follow the peer so identified to improve agility activities to become competitive. However, the study considers limited data due to unavailability of many agile organizations. As agile manufacturing is relatively a new concept, certain and complete information on systems are not available. In such situations, the proposed method can deal the issue conveniently and results in workable solutions.

4.2.2 Background

Today's manufacturing companies are facing fierce competition due to globalization, market instability and dynamic requirement of customers in terms of price, specifications, quality, quantity and delivery. Therefore, industries adopt proactive strategies with due consideration to the consumer's awareness and fierce competition with shorter product life cycles, quicker delivery of new products to market and decrease in operating costs. Time based manufacturing is capable of continually delivering new products quickly to the market and increases the varieties offered to the customers through continuous introduction of innovative technology. The success of time based manufacturing has emerged as a new paradigm in manufacturing known as mass customization (MC) (Silverira et al., 2001). The term mass customization, coined by Davis (1989), is directed to produce goods and services to meet individual customer's requirement with mass production efficiency through high process flexibility and integration. Mass customizers develop, produce, market and distribute a wide variety of products and services to suit individual needs at an affordable price. In the process of shifting to MC, the organizations concentrate on agile manufacturing, because, an agile manufacturing system can respond the trend of mass customization in an effective manner. Agility is the set of ability of an organization for meeting dynamic customer requirement achieved through advanced organizational and managerial structure, some concrete technological achievement (Deschamps et al., 1995; Nagel et al., 1991). Agile manufacturing has several directions like strategic planning, product design, automation, advanced information technology, virtual enterprise (Hayes et al., 1988; Ettlie, 1988). Agility evaluation is the vital issue in strategic planning to determine the degree of agility an organization currently possesses. Agility evaluation helps the managers to formulate strategic plans by determining how much an organization needed to be agile. To achieve an appropriate strategic plan, the business decision mechanism is usually composed of multiple experts who implement decision analysis and alternatives evaluation on the basis of association rules and criterions. Evaluating the alternatives and comparing across them, the best practices can be found out and transferred to different organizations. In any decision-making process, there exists considerable extent of uncertainty, fuzziness and heterogeneity (Chen and Hwang, 1992). Since there is no well-defined process and vague indicators exist to access agility degree, agility evaluation is difficult to be handled by crisp values. Fuzzy logic is a useful tool to deal ambiguities, uncertainties and vagueness the in agility evaluation (Zadeh, 1965). However, the condition of fuzziness cannot be considered in fuzzy multi attribute decision making process (MADM). Therefore, a method, which is simple, practical and demands less practical information, like grey theory can be adopted for agility evaluation and comparing among various organizations that intend to go for mass customization. It has been demonstrated that grey theory can deal flexibly with the fuzziness situation (Li et al., 2007a, b; Deng, 1996). The present work aims at establishing an agile alternative evaluation approach for MC manufacturing system. The methods result in ranking of various agile manufacturing systems using grey theory approach. In latter part, the results, obtained thereof, have been compared with another existing MADM approach: fuzzy-TOPSIS for believability and adoptability.

4.2.3 State of Art and Problem Statement

A Petri Nets approach using state space probabilities was proposed to determine the complexity measure as a surrogate measure of agility. The method was unable to identify potential changes needed for a system to respond to become agile (Arteta and Giachetti, 2004). An enhanced flexible approach based on fuzzy association rule mining was proposed to support the decision makers for evaluating agility with various attributes such as flexibility, profitability, quality, innovativeness, pro-activity, and speed of response, cost and robustness (Jain et al., 2008).

An analytical framework was developed for evaluation of the degree of agility and the method could be used to rationally select an appropriate agile method for a particular application (Qumer and Handerson-Sellers, 2008). A metrics method was proposed for determining enterprise agility which could be extended to other technological decisions (Ganguly et al., 2009). Chandna (Kharbanda) (2008) presented a fuzzy logic based framework incorporating certain operational parameters for the assessment of manufacturing agility only. A test bed was used to simulate, measure, and evaluate agility and its parameters. Wang (2009) proposed an MC manufacturing agility evaluation approach based on the concept of TOPSIS through various agility evaluation platforms.

A 2-tuple fuzzy linguistic computing method was proposed to transform the heterogeneous information assessed by multiple experts into an identical decision domain. An agility index measurement model containing twenty criteria incorporated with multi-grade fuzzy approach was designed for agile evaluation of a single manufacturing organization (Vinodh et al., 2010a).

An absolute agility index was proposed using fuzzy logic to address the ambiguity inherent in agile evaluation (Lin et al., 2006a, b). A fuzzy analytic network process (ANP) was proposed for agile concept selection in a single manufacturing organization (Vinodh et al., 2010c). In the past, a large body of literature was devoted to agile evaluation in multi attribute decision making framework (MADM).

Several techniques were developed and reported in literature towards solving MADM problems. Some of the popular methods include linear weighting methods (LW) (Cebi and Bayraktar , 2003; Boer et al.,1998; Gregory,1986; Li et al.,1997; Soukup, 1987; Thompson, 1990; Timmerman,1986; Willis et al.,1993), ANP (Sarkis and Talluri, 2000), total cost approaches (Monczka and Trecha, 1998; Smytka and Clemens, 1993) and mathematical programming techniques (Buffa and Jackson, 1983; Chaudhry et al., 1993; Das and Tyagi, 1994; Pan, 1989; Weber and Current, 1993). Although linear weighting method is simple, it depends largely on human judgment and weighs the attributes equally, which rarely happens in practice. Mathematical programming technique causes significant problems while considering qualitative factors. Such techniques include goal programming (Hajidimitriou and Georgiou, 2002), linear programming (Ghodsypour and O'Brien, 1998) and mixed-integer programming (Rosenthal et al., 1995). Although both analytic hierarchy process (AHP) and mathematical programming have some advantages over other existing approaches they are still suffering from some drawbacks. AHP cannot effectively take into account risk and uncertainty in estimating the performance of the alternative, because, it presumes that the relative importance of attributes affecting the alternative's performance is known with certainty (Dyer et al., 1992). The drawback of mathematical programming is that it requires arbitrary aspiration levels and cannot accommodate subjective attributes (Khorramshahgol et al., 1988). Wang and Chang (2007) developed an evaluation approach based on TOPSIS to help the Air Force Academy in Taiwan for choosing optimal initial training aircraft. But in classical MADM methods, the ratings and the weights of the criteria are known precisely. A mass customization product manufacturing agility evaluation index was proposed using multi-grade fuzzy assessment method studying an enterprise's organization management agility, products design agility, and manufacturing agility (Yang and Li, 2002).

Considering limitations of the above techniques, this work proposes a simple but an effective method based on grey relation analysis as a means to reflect uncertainty in multi-attribute decision making models. Grey system theory was developed by Deng (1989) based upon the concept that information is sometimes incomplete or unknown. The intent is the same as with factor analysis, cluster analysis and discriminate analysis except that these methods often do not work well when sample size is small and sample distribution is unknown (Wang et al., 2004). The advantage of grey theory over fuzzy logic (Zadeh, 1965) is that grey theory considers the condition of the fuzziness; in other words, grey theory can deal flexibly with the fuzziness situation (Li et al., 2007). Grey relation analysis and TOPSIS (Hwang and Yoon, 1981; Lai et al., 1994; Yoon and Hwang, 1995) both use the idea of minimizing a distance function. To evaluate and rank alternatives by developing a heterogeneous information aggregation platform is indispensable for robust business mechanism. This research focuses on establishing an agility measurement approach based on concept of Grey relational analysis and fuzzy-TOPSIS for mass customization manufacturing system.

4.2.4 Agility Evaluation Platform

Organizations must exhibit agility in response to changing needs of the market was originally popularized by US agility forum (Nagel et al., 1991). As there is hourly changeover in the production lots, an agile manufacturing system is necessary to settle on for producing mass customized products. MC enterprise uses a series of advanced information technology, modern management technology and advanced manufacturing technology with an aim at enriching customers through agile response to customer demand, market change and market opportunities. There are two questions concerning agility arise: how it is measured and the principal obstacles to improve agility (Sharp et al., 1999; James-Moore, 1997; Long, 2000; Yusuf et al., 2001). Therefore, research is going on to solve these problems starting with more emphasis upon agile evaluation which helps the managers in organizing the activities to become agile. Agility has three underlying components delivering value to customers - being ready for change, valuing human knowledge and skills and forming virtual partnerships (Sanchez and Nagi, 2001). Critical examination of literature reveals that main agility entries for evaluation of MC product system are as follows.

Organization management agility

It includes inter-organization cooperative extent, the speed of team building, network connection extensiveness, the application degree of the virtual enterprise (VE) and so on.

Product design agility

It includes the design period, the proportion of design period in product periods, the seriating degree of products, and the generalization degree of products structure. It measures the speed of period of product design and flexibility in the design.

Processing manufacture agility

It comprehends the time organizational form of the production process, the space organizational form of production process, displacement compatibility, reconfigurable flexibility, supplement tool displacement and so on. In order to achieve agility, a combination of certain desirable characteristics is needed like combination of multipurpose machines and fixtures, redundant equipment material handling devices and process variety.

Partnership formation agility

It encompasses the degree of cooperation with other enterprises, institutional framework agility, and the form of institutional framework and so on. The agile manufacturers should change the way they interact with their business partners so that they can compete more effectively through cooperation.

Integration of information system

It contains information and network utilization rate, perfect degree of information system, swift way of getting customer demand information, the proportion of information processing time in product periods and so on. It is measured in terms of networking which includes the communication capabilities of an enterprise and defined through ability to exchange information.

Therefore, MC enterprises are required to possess the above abilities of an agile system. This work uses grey relational analysis, a MADM framework, to rank the alternatives (organizations) evaluating agility of each organization with due consideration to above abilities (criteria).

4.2.5 Grey and Fuzzy-TOPSIS Based Appraisement Modeling

Grey based decision making approach proposed for agile evaluation and ranking of alternatives are presented below. Grey theory is one of the methods to study systems with uncertain information mathematically. Consider $A = \{A_1, A_2, A_{3,} ....A_m\}$ is a discrete set of m possible alternatives and $L = \{L_1, L_{2,}, L_3,...., L_n\}$ is a set of n criteria for selecting alternatives. The criteria are assumed to be additively independent and $\otimes w = \{\otimes w_1, \otimes w_2, \otimes w_3,... \otimes w_n\}$ represent the vector of criteria weights. The linguistic variables can be expressed in grey numbers using a 0-1 and 0-10 scale for attributes and attribute ratings as shown in Table 4.10 and Table 4.11, respectively (Li et al., 2007a, b).

Step 1: Form a committee of decision-makers and identify the criteria weights of alternatives by aggregating the weights of importance. Many methods have been proposed to pool the decision makers' opinions, for example mean, median, max, min etc. Each of operators has its own limitations. Criteria for selecting appropriate aggregation operator can be found out .Since the average operation is the most commonly used aggregation method; the mean operator is used to aggregate the decision makers' assessments. Assume that a decision group has K persons, then the criteria weight can be calculated as

$$\otimes w_j = \frac{1}{k}\left[\otimes w_j^1 + \otimes w_j^2 + ...+ \otimes w_j^k\right] \tag{4.3}$$

where $\otimes w_j^k (j = 1,2,.....,n)$ is the criteria weight of k^th decision maker and can be described by grey number $\otimes w_j^k = \left[\underline{w}_j^k, \overline{w}_j^k\right]$.

Step 2: Use linguistic variables for the ratings to make a criteria rating value. Then, the rating value can be calculated as:

$$\otimes G_{ij} = \frac{1}{k}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + ... + \otimes G_{ij}^k\right] \tag{4.4}$$

where $\otimes G_{ij}^k (i = 1,2,....., m; j = 1,2,....., n)$ is the criteria rating of i^th alternative under j^th criterion by k^th decision maker and can be described by grey number $\otimes G_{ij}^k = \left[\underline{G}_{ij}^k, \overline{G}_{ij}^k\right]$.

Step 3: Establish the grey decision matrix

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & .... & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & .... & \otimes G_{2n} \\ .... & .... & .... & .... \\ \otimes G_{m1} & \otimes G_{m2} & .... & \otimes G_{mn} \end{bmatrix} \tag{4.5}$$

where $\otimes G_{ij}$ are linguistic variables based on the grey number.

Step 4: Normalize the grey decision matrix

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \otimes G_{12}^* \ldots\ldots \otimes G_{1n}^* \\ \otimes G_{21}^* & \otimes G_{22}^* \ldots\ldots \otimes G_{2n}^* \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & \\ \otimes G_{m1}^* & \otimes G_{m2}^* \ldots\ldots \otimes G_{mn}^* \end{bmatrix} \tag{4.6}$$

$$\otimes G_{ij}^* = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}} \right]$$

$$G_j^{max} = \max_{1 \le i \le m} \left\{ \overline{G}_{ij} \right\}$$

for a non-benefit criteria, $\otimes G_{ij}^*$ is expressed as

$$\otimes G_{ij}^* = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}} \right]$$

$$G_j^{min} = \min_{1 \le i \le m} \left\{ \underline{G}_{ij} \right\}$$

The normalization method mentioned above preserves the property that the ranges of the normalized grey number belong to [0, 1].

Step 5: Establish the weighted normalized grey decision matrix. Considering the different importance of each criterion, the weighted normalized grey decision matrix can be established as

$$D^* = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} \ldots\ldots\ldots\ldots \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} \ldots\ldots\ldots\ldots \otimes V_{2n} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots & \\ \otimes V_{m1} & \otimes VG_{m2} \ldots\ldots\ldots \otimes V_{mn} \end{bmatrix} \tag{4.7}$$

where $\otimes V_{ij} = \otimes G_{ij}^* \times \otimes w_j$

Step 6: Make the ideal alternative as a referential alternative. For m possible alternatives set $A = \{A_1, A_2, ..., A_m\}$, the ideal referential agile alternative $A^{max} = \{\otimes G_1^{max}, \otimes G_2^{max}, ..., \otimes G_n^{max}\}$ can be obtained by

$$A^{max} = \left\{\left[\max_{1 \le i \le m} \underline{V}_{i1}, \max_{1 \le i \le m} \overline{V}_{i1}\right], \left[\max_{1 \le i \le m} \underline{V}_{i2}, \max_{1 \le i \le m} \overline{V}_{i2}\right], ..., \left[\max_{1 \le i \le m} \underline{V}_{in}, \max_{1 \le i \le m} \overline{V}_{in}\right]\right\}. \qquad (4.8)$$

Step 7: Calculate the grey possibility degree between compared alternatives set $A = \{A_1, A_2, ..., A_m\}$ and ideal referential agile alternative A^{max}.

$$P\{A_i \le A^{max}\} = \frac{1}{n} \sum_{j=1}^{n} P\{\otimes V_{ij} \le \otimes G_j^{max}\} \qquad (4.9)$$

Step 8: Rank the order of agile alternatives, when $P\{A_i \le A^{max}\}$ is smaller, the ranking order of alternative is better. Otherwise, the ranking order is worse. According to the above procedures, one can determine the ranking order of all agile alternatives and select the best from among a set of feasible alternatives.

Table 4.10: The scale of attribute weights w

Linguistic Scale	$\otimes w$
Very Low (VL)	[0.00,0.15]
Low (L)	[0.15,0.30]
Medium Low (ML)	[0.30,0.45]
Medium (M)	[0.45,0.60]
Medium High (MH)	[0.60,0.75]
High (H)	[0.75,0.90]
Very high (VH)	[0.90,1.00]

Table 4.11: The scale of attribute ratings G

Linguistic Scale	$\otimes G$
Very Poor (VP)	[0.0,1.0]
Poor (P)	[1.0,2.5]
Medium Poor (MP)	[2.5,4.0]
Fair (F)	[4.0,5.5]
Medium Good (MG)	[5.5,7.0]
Good (G)	[7.0,8.5]
Very Good (VG)	[8.5,10.0]

4.2.6 Results and Discussions

As a case study, the agility evaluation problem in an automotive industry in eastern part of India has been explored. Multiple attributes should be taken under consideration while selecting an appropriate alternative. Thus, agile alternative ranking and selection of the best alternative have been made. A committee of four decision makers $D_1, D_2., D_3, D_4$ have been formed to conduct the evaluation. Four feasible agile systems A_1, A_2, A_3, A_4 have been chosen for evaluation. The alternative A_1 is characterised by extensive outsourcing facility, high level product service, adequate design improvement through in-house Research and Development, and fully automated inspection system. However, alternative A_3 possess these characteristics at low level. For other two alternatives A_2, A_4, these characteristics are in medium level. For achieving agility to improve mass customization, five agile criteria are considered. They are (i) Organization management agility (L_1), (ii) Product design agility (L_2), (iii) Processing manufacture agility (L_3), (iv) Partnership formation agility (L_4), and (v) Integration of Information system (L_5). The steps 1 to 8 are shown below.

Step 1: The weights of attributes L_1, L_2, L_3, L_4 and L_5 have been determined. A committee of four decision-makers D_1, D_2, D_3, and D_4 has been formed to express their preferences and to select the best agile manufacturer. Here, a weight of each attribute has been obtained as shown in Table 4.12 by averaging responses of experts.

Step 2: The attribute rating values for four agile alternatives are determined. According to Eq. 4.4, the results of attribute rating values are shown in Table 4.13.

Table 4.12: Attribute weights for five criteria

L_J	D_1	D_2	D_3	D_4	$\otimes$ W_J
L_1	H	VH	VH	H	[1.00,2.75,3.50]
L_2	VH	H	H	H	[1.00,2.37,3.50]
L_3	M	MH	H	MH	[0.8,1.22, 3.00]
L_4	MH	MH	H	H	[0.95,1.50,3.00]
L_5	VH	MH	H	H	[0.95,2.12,3.50]

Table 4.13: Attribute ratings for alternatives

	Ai	D_1	D_2	D_3	D_4	$\otimes G_{IJ}$
L_1	A_1	VG	G	MG	MG	[6.6,8.4]
	A_2	F	MG	G	G	[5.9,7.4]
	A_3	MG	F	F	MG	[4.8,6.25]
	A_4	G	MG	F	G	[5.9,7.4]
L_2	A_1	G	MP	F	MG	[4.8,6.3]
	A_2	MG	G	MG	MG	[5.9,7.4]
	A_3	G	MP	MG	P	[4.0,5.5]
	A_4	P	MG	MP	F	[3.3,4.8]
L_3	A_1	MG	G	MP	F	[4.8,6.3]
	A_2	P	VP	F	MG	[2.63,4.0]
	A_3	F	MP	P	MG	[3.3,4.8]
	A_4	F	F	MP	MP	[3.3,4.8]
L_4	A_1	P	P	MP	MP	[1.8,3.3]
	A_2	F	MP	P	F	[2.9,4.44]
	A_3	VP	P	MP	MP	[1.5,2.9]
	A_4	F	MP	P	MP	[2.5,4.0]
L_5	A_1	G	G	MG	MG	[6.3,7.8]
	A_2	P	MP	F	P	[2.12,3.63]
	A_3	VP	P	P	MP	[1.12,2.5]
	A_4	MG	G	MP	F	[4.8,6.3]

Step 3: The grey decision matrix has been established. According to Eq. 4.5, the grey decision matrix of alternatives obtained and shown in Table 4.14.

Table 4.14: Grey decision-matrix

A_i	L_1	L_2	L_3	L_4	L_5
A_1	[6.6,8.4]	[4.8,6.3]	[4.8.6.3]	[1.8,3.3]	[6.3,7.8]
A_2	[5.9,7.1]	[5.9,7.4]	[2.63,4.0]	[2.9,4.4]	[2.12,3.63]
A_3	[4.8,6.25]	[4.0,5.5]	[3.3,4.8]	[1.5,2.9]	[1.12,2.5]
A_4	[5.9,7.4]	[3.3,4.8]	[3.3,4.8]	[2.5,4.0]	[4.8,6.3]

Step 4: Then, the grey normalized decision table has been formed. According to the Eq. 4.6, the grey normalized decision matrix table shown in Table 4.15.

Table 4.15: Grey normalized decision-matrix

A_i	L_1	L_2	L_3	L_4	L_5
A_1	[0.79,1.00]	[0.65,0.85]	[0.762,0.1.00]	[0.4,0.75]	[0.81,1.00]
A_2	[0.702,0.85]	[0.79,1.00]	[0.42,0.63]	[0.66,1.00]	[0.27,0.466]
A_3	[0.571,0.74]	[0.54,0.74]	[0.53,0.76]	[0.34,0.66]	[0.14,0.32]
A_4	[0.702,0.88]	[0.45,0.65]	[0.53,0.762]	[0.57,0.91]	[0.62,0.81]

Step 5: The grey weighted normalized decision table has been established. According to the Eq. 4.7, the grey weighted normalized decision table has been shown in Table 4.16.

Table 4.16: Grey weighted normalized decision matrix

A_i	L_1	L_2	L_3	L_4	L_5
A_1	[0.66,.95]	[.372,.567]	[.228,.341]	[.503,.755]	[0.61,0.89]
A_2	[0.58,0.81]	[0.62,0.93]	[0.25,0.47]	[0.44,0.83]	[0.20,0.41]
A_3	[0.47,0.70]	[0.43,0.69]	[0.31,0.57]	[0.22,.755]	[0.10,0.28]
A_4	[0.58,0.84]	[0.36,0.60]	[0.31,0.57]	[0.38,0.75]	[0.46,0.72]

Step 6: The ideal agile manufacturer A^{max} taken as a referential alternative. According to Eq. 4.8, the ideal A^{max} alternative has been shown as follows:

A^{max} ={[0.66,0.95],[0.62,0.93],[0.46,0.75],[0.44,0.83],[0.61,0.89]}

Step7: The grey possibility degree between compared alternatives set $A=\{A_1,A_2,......A_4\}$ and ideal referential supplier alternative A^{max} calculated. According to Eq. 4.9, the results of the grey possibility degree are shown as follows:

$P(A_1 \leq A_{max}) = 0.584$ $\quad$ $P(A_2 \leq A_{max}) = 0.74$

$P(A_3 \leq A_{max}) = 0.892$ $\quad$ $P(A_4 \leq A_{max}) = 0.771$

The smaller one is better.

Step 8: According to Step 7, which is the outcome of the grey based method, the result of ranking order is shown as follows: $A_1 \rangle A_2 \rangle A_4 \rangle A_3$

It can, therefore, be concluded that the agile system A_1 is the best out of the four. Also A_2 should be an important alternative. The next important alternative is A_4 whereas A_3 is the worst as far as agility is concerned.

TOPSIS is known as one of the most classical MADM methods based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other side the farthest distance from the negative ideal solution (Hwang and Yoon, 1981). In classical MADM methods, the ratings and the weights of the criteria are known precisely. However, in real word situation, because of incomplete or non-obtainable information, for example, human judgments including preferences are often vague and difficult to estimate preferences with exact numerical data; rather data (attributes) are usually fuzzy or imprecise (Chen and Hwang, 1992; Zadeh,1965). Therefore, fuzzy-TOPSIS is used to efficiently handle the fuzziness of the data involved in the decision making for agility evaluation. Such type of approaches have been used in the past in various decision making situations (Wang and Chang, 2007; Kahraman et al., 2007; Abo-Sinna and Amer, 2005; Abo-Sinna et al., 2008). In order to compare the ranking of agile enterprises obtained through grey-based decision making approach, the well-known approach used for such purpose like fuzzy-TOPSIS. Triangular fuzzy numbers appear as useful means of quantifying the uncertainty in decision making due to their intuitive appeal and computation efficacy representation.

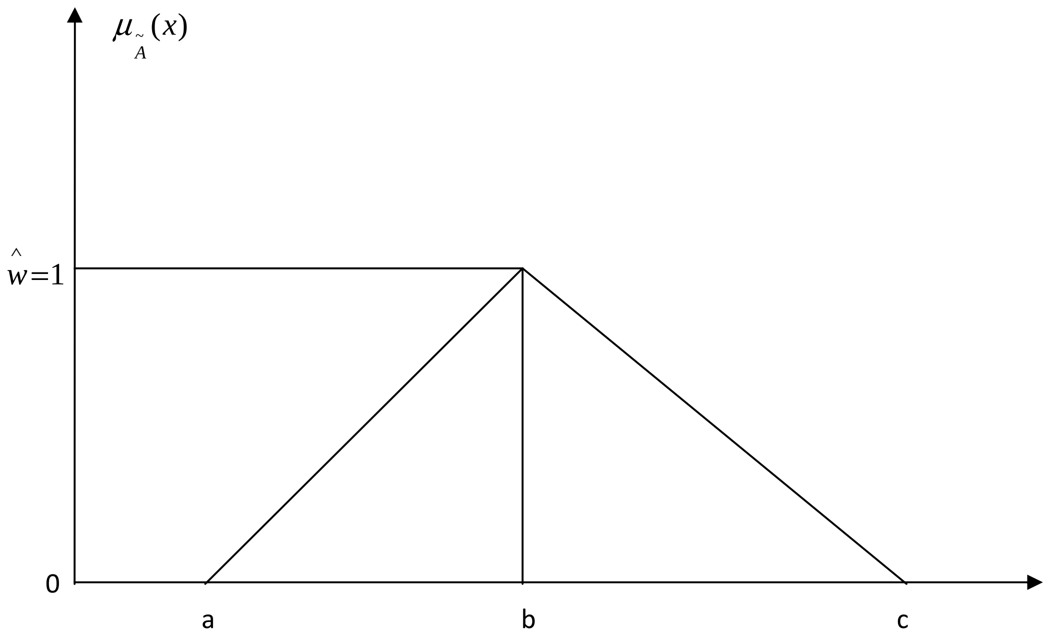

Fig 4.1: A triangular fuzzy number

The triangular fuzzy numbers (TFN) can be denoted as $\tilde{A} = (a,b,c)$ illustrated in Fig. 4.1, where the parameter a indicates the smallest possible value, b the most promising value and c indicates the largest possible value The corresponding membership function $\mu_{\tilde{A}}(x)$ is defined as:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-a)/(b-a), & a \le x \le b \\ (x-c)/(b-c), & b \le x \le c, \\ 0, & \text{otherwise} \end{cases} \tag{4.10}$$

MC manufacturing agility evaluation based on concept of fuzzy TOPSIS has been carried out using same five criteria such as agility of organization management, product design, processing manufacturer, partnership formation capability and integration of information system. The five criteria are denoted as L_1, L_2, L_3, L_4, and L_5. There have been the same four decision-makers (expert group) denoted as D_1, D_2, D_3, and D_4. The number of alternatives or agile organizations has again been same four as A_1, A_2, A_3, and A_4. The linguistic variables selected for evaluating weight of each criterion and ratings of alternatives have been shown in Table 4.17 and Table 4.18, respectively.

Table 4.17: Linguistic variables for importance weight of each criterion

Linguistic Scale	Weights
Very Low (VL)	[0.00,0.00,0.30]
Low (L)	[0.15,0.30,0.45]
Medium Low (ML)	[0.30,0.60,0.90]
Medium (M)	[0.80,0.90,1.00]
Medium High (MH)	[0.95,1.00,1.05]
High (H)	[1.00,2.00,3.00]
Very high (VH)	[2.50,3.50,3.50]

Table 4.18: Linguistic variables for appropriateness ratings

Linguistic Scale	Ratings
Very Poor (VP)	[0.0,0.0,1.0]
Poor (P)	[0.5,1.0,1.5]
Medium Poor (MP)	[1.0,2.0,3.0]
Fair (F)	[2.5,3.0,3.5]
Medium Good (MG)	[3.0,4.0,5.0]
Good (G)	[4.5,5.0,5.5]
Very Good (VG)	[5.0,6.0,6.0]

The heterogeneous information generated from decision-makers has been transformed by aggregating the weight of criteria. If the fuzzy ratings of multiple-experts for various criteria are described by fuzzy numbers $\tilde{R}_K = (a_k, b_k, c_k)$ where k = 1,2,…k, then aggregated fuzzy rating determined by $\tilde{R}$ =(a, b, c). Here,

$$a = \min_k\{a_k\},\ b = 1/k\sum_{k=1}^{k} b_k,\ c = \max_k\{c_k\} \tag{4.11}$$

Each decision maker uses the linguistic variables given in Table 4.17 for assigning weight of each criterion. The criteria weight by each decision maker is shown in Table 4.19. The weights have been aggregated using Eq. 4.11.

The decision-makers have been instructed to use the linguistic variables shown in Table 4.18 to evaluate the ratings of alternatives with respect to each criterion. The aggregated ratings of four alternatives under five criteria have been shown in Table 4.20 using Eq. 4.11. Then, fuzzy decision-matrix (determined from Table 4.20) has been shown in Table 4.21 along with the criteria weights.

The fuzzy decision matrix has been normalized next. The linear scale transformation has been used here to transform various criteria in to comparable scale. If the rating of a criterion i under alternative j is given by (a_{ij}, b_{ij}, c_{ij}), then the normalized fuzzy ratings can easily be obtained using Eq. 4.12, because, all the criteria have been assumed benefit in-nature, considered in this study. The weighted normalized fuzzy decision matrix has been shown in Table 4.22.

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$$
$$c_j^* = \max_i c_{ij} \tag{4.12}$$

Table 4.19: Importance weight of criterions

	D_1	D_2	D_3	D_4	Weights
L_1	H	VH	VH	H	[1.00,2.75,3.50]
L_2	VH	H	H	H	[1.00,2.37,3.50]
L_3	M	MH	H	MH	[0.8,1.22, 3.00]
L_4	MH	MH	H	H	[0.95,1.50,3.00]
L_5	VH	MH	H	H	[0.95,2.12,3.50]

Table 4.20: Attribute ratings for alternatives

	A_i	D_1	D_2	D_3	D_4	Ratings
L_1	A_1	VG	G	MG	MG	[3.0,4.75,6.0]
	A_2	F	MG	G	G	[2.5,4.37,5.5]
	A_3	MG	F	F	MG	[2.5,3.5,5.0]
	A_4	G	MG	F	G	[2.5,4.25,5.5]
L_2	A_1	G	MP	F	MG	[1.00,3.5,5.5]
	A_2	MG	G	MG	MG	[3.0,4.25,5.5]
	A_3	G	MP	MG	P	[0.5,3.0,5.5]
	A_4	P	MG	MP	F	[0.5,2.5,5.5]
L_3	A_1	MG	G	MP	F	[1.0,3.50,5.5]
	A_2	P	VP	F	MG	[0.0,2.0,5.0]
	A_3	F	MP	P	MG	[0.5,2.5,5.0]
	A_4	F	F	MP	MP	[1.0,2.5,3.5]
L_4	A_1	P	P	MP	MP	[0.5,1.5,3.0]
	A_2	F	MP	P	F	[0.5,2.25,3.5]
	A_3	VP	P	MP	MP	[0.0,1.25,3.0]
	A_4	F	MP	P	MP	[0.5,2.0,3.5]
L_5	A_1	G	G	MG	MG	[3.0,4.5,5.5]
	A_2	P	MP	F	P	[0.5,1.75,3.5]
	A_3	VP	P	P	MP	[0.0,1.0,3.0]
	A_4	MG	G	MP	F	[1.0,3.5,5.5]

Table 4.21: Fuzzy decision-matrix and corresponding fuzzy weights

Criteria/Alternatives	A_1	A_2	A_3	A_4	Weight
L_1	[3.0, 4.75, 6.0]	[2.5, 4.37, 5.5]	[2.5, 3.5, 5.0]	[2.5, 4.25, 5.5]	[1.0, 2.75, 3.5]
L_2	[1.0, 3.5, 5.5]	[3.0, 4.25, 5.5]	[0.5, 3.0, 5.5]	[0.5, 2.5, 5.0]	[1.0, 2.37, 3.5]
L_3	[1.0, 3.5, 5.5]	[0.0, 2.0, 5.0]	[0.5, 2.5, 5.0]	[1.0, 2.5, 3.5]	[0.8, 1.22, 3.0]
L_4	[0.5, 1.5, 3.0]	[0.5, 2.25, 3.5]	[0.0, 1.25, 3.0]	[0.5, 2.0, 3.5]	[0.95, 1.5, 3.0]
L_5	[3.0, 4.5, 5.5]	[0.5, 1.75, 3.5]	[0.0, 1.0, 3.0]	[1.0, 3.5, 5.5]	[0.95, 2.12, 3.0]

The weighted normalized decision-matrix has been determined next. The weighted normalized decision-matrix has been obtained simply by multiplying the importance weights of evaluation criteria and the values in the normalized fuzzy decision matrix. The weighted normalized decision-matrix has been shown in Table 4.23.

The fuzzy positive ideal solution (A*) and fuzzy negative ideal solution (A^-) have been determined as follows from Table 4.23.

$A^* =$ =[(3.5,3.5,3.5),(3.5,3.5,3.5),(2.73,2.73,2.73),(1.92,1.92,1.92), (3.5,3.5,3.5)]

A^- =[(0.45,0.45,0.45),(0.09,0.09,0.09),(0,0,0), (0,0,0), (0,0,0)]

The distance of each alternative from A* and A^- have been calculated by *vertex method*. The results of all alternatives distances from *Fuzzy Positive Ideal Solution* (FPIS) and *Fuzzy Negative Ideal Solution (FNIS)* have been shown in Table 4.24 and Table 4.25, respectively.

In the TOPSIS method, the closeness coefficient (CC_i) for each alternative is defined to determine the ranking order of all alternatives. The distance from positive ideal solution d^* and negative ideal solution d^- of each alternative have been calculated (Table 4.26).

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, i = 1,2,...,m \tag{4.13}$$

According to the CC_i, the ranking order of all alternatives can be determined and thereby, the best alternative from among a set of feasible alternatives can be selected. The higher value of CC_i indicates that an alternative is closer to the positive ideal solution and farther from the negative ideal solution, simultaneously. A value of 1 (or 100 per cent) for an alternative indicates that the alternative is equal to the positive ideal solution and a value of 0 (or 0 per cent) is equal to the negative ideal solution. The best alternative is the one with the greatest relative closeness to the positive ideal solution.

According to the closeness coefficient (Table 4.27), the ranking order of four alternatives has been determined as follows:

$A_1 \rangle A_2 \rangle A_4 \rangle A_3$

The first agile alternative has been determined as the most appropriate alternative. It is to be noted that the ranking obtained via grey based approach is similar to ranking of alternatives obtained by fuzzy-TOPSIS method.

Here, it is demonstrated that grey based method and fuzzy-TOPSIS results in same order of ranking for the agile alternatives. The first alternative is the best for providing the comprehension of manufacturing features in mass customization through proposed agility index by related dimensions of management and technology. Although grey based method and fuzzy-TOPSIS are both appropriate for multi-criteria decision making problem, grey based approach is intuitively appealing due to less computational effort and simplicity in structure. The normalization procedure in grey based approach is simple and logical as compared to fuzzy TOPSIS method. The ranking values shown in Table 4.27 have been plotted in Fig. 4.2. It can be easily noted that the grey based approach clearly provides distinction among the alternatives because high degree of variation of ranking values has been observed. However, sometimes the ranking values in case of fuzzy-TOPSIS may not be distinguishable.

Table 4.22: Normalized fuzzy decision-matrix

Criteria/Alternatives	A_1	A_2	A_3	A_4
L_1	[0.5, 0.79, 1.0]	[0.45, 0.79, 1.0]	[0.45, 0.64, 0.91]	[0.45, 0.77, 1.0]
L_2	[0.17, 0.58, 0.91]	[0.5, 0.71, 1.0]	[0.09, 0.54, 1.0]	[0.09, 0.45, 0.91]
L_3	[0.17, 0.58, 0.91]	[0.0, 0.33, 0.91]	[0.09, 0.45, 0.91]	[0.18, 0.45, 0.64]
L_4	[0.08, 0.25, 0.50]	[0.09, 0.41, 0.64]	[0.0, 0.23, 0.54]	[0.09, 0.36, 0.64]
L_5	[0.50, 0.75, 0.92]	[0.09, 0.32, 0.64]	[0.0, 0.18, 0.54]	[0.18, 0.64, 1.0]

Table 4.23: Weighted normalized fuzzy decision-matrix

Criteria/Alternatives	A_1	A_2	A_3	A_4
L_1	[0.5, 2.17, 3.50]	[0.45, 2.17, 3.5]	[0.45, 1.76, 3.18]	[0.45, 2.11, 3.5]
L_2	[0.17, 1.37, 3.18]	[0.5, 1.68, 3.5]	[0.09, 1.28, 3.5]	[0.09, 0.16, 3.18]
L_3	[0.14, 0.71, 2.73]	[0.0, 0.402, 2.73]	[0.07, 0.55, 2.73]	[0.14, 0.55, 1.92]
L_4	[0.076, 0.37, 1.5]	[0.76, 0.62, 1.92]	[0.0, 0.34, 1.62]	[0.08, 0.54, 1.92]
L_5	[0.47, 1.59, 3.22]	[0.08, 0.68, 2.24]	[0.0, 0.38, 1.89]	[0.17, 1.36, 3.50]

Table 4.24: Distance between A_i (i=1, 2, 3, 4) and A^* with respect to each criterion

Criteria/Alternatives	L_1	L_2	L_3	L_4	L_5
$d(A_1, A^*)$	1.895	2.29	1.90	1.41	2.07
$d(A_2, A^*)$	1.920	2.03	2.07	1.30	2.66
$d(A_3, A^*)$	2.040	2.35	1.99	1.45	2.86
$d(A_4, A^*)$	1.940	2.76	2.09	1.33	2.29

Table 4.25: Distance between A_i (i=1, 2, 3, 4) and A^- with respect to each criterion

Criteria/Alternatives	L_1	L_2	L_3	L_4	L_5
$d(A_1, A^-)$	2.02	1.93	1.63	0.89	2.09
$d(A_2, A^-)$	2.02	2.19	1.59	0.17	1.35
$d(A_3, A^-)$	1.75	2.09	1.61	0.96	1.11
$d(A_4, A^-)$	2.00	1.78	1.16	1.15	2.17

Table 4.26: Computation of d_i^*, d_i^- and CC_i

	A_1	A_2	A_3	A_4
d_i^*	9.565	9.980	10.690	10.410
d_i^-	8.560	7.320	7.520	8.260
CC_i	0.470	0.450	0.450	0.440

Table 4.27: Computed values of $P(A_i \leq A_{max})$ and CC_i

	$P(A_i \leq A_{max})$	CC_i
A_1	0.584	0.470
A_2	0.740	0.450
A_3	0.892	0.410
A_4	0.771	0.440

4.2.7 Concluding Remarks

Multi attribute decision making (MADM) has been used to select an alternative from several alternatives according to various criteria. The uncertainty and vagueness always face up by decision makers in the decision making process from subjective perception and experience. In conventional MADM problems, the ratings and the weights of the attributes must be known precisely. The input information in many situations is often uncertain and cannot be estimated by an exact numerical value. In ranking of agile manufacturers (for mass customization) has many uncertainties, because, the concept of agility has not been percolated into industries extensively. Therefore, linguistic evaluation models for selecting appropriate agile-based manufacturing system to catch the traits involved in mass customization have been proposed in this study. The procedures of grey based and fuzzy TOPSIS decision making shows how to reach at a more effective decision dealing with uncertainty and vagueness from subjective perception. Both the methods concentrate on application of linguistic approximation to address agility capability measurement. Although both the methods results in same order of ranking for the alternatives, grey based approach is intuitively appealing due to less computation effort and logical process of normalization. The approach can take into account the condition of fuzziness and works well for smaller data set. The ranking values obtained by grey based approach are quite distinguishable so that ambiguity can be avoided in final decision making.

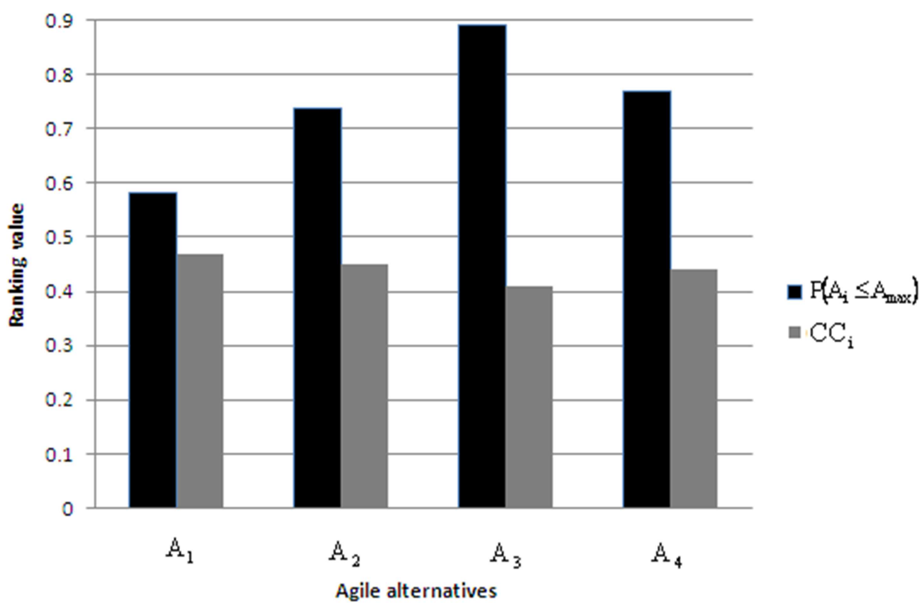

Fig 4.2: Comparison of grey method and Fuzzy-TOPSIS for four agile alternatives

4.3 Agility Evaluation in Fuzzy Context: Influence of Decision-Makers' Risk Bearing Attitude

4.3.1 Overview

The second millennium draws attention for major paradigm shift in manufacturing sectors. As a result every next moment a new window is being opened for manufacturing. The competitive priority of manufacturing firms gradually shifted from '*cost*' in *1960s* to '*time*' at present. During *1950-60s*, the strategic trend in industries was viewed towards cost reduction but it was shifted to production in *1960-70s*; product quality in *1970-80s*; the concept of *Just-In-Time (JIT)* and *lean manufacturing* came into picture during *1980-90s*.

In upcoming competitive era, successful survival to face '*ever-changing environment'* in global business scenario is one of the major thrust areas for every manufacturing cum production units. Industries are frequently facing unpredictable, high-frequency market changes stimulated by technological innovations, turbulence in marketplace, and dynamic customer demand/ expectations. Increased fierce competition in the market is indeed inevitable today which is driven by the world economy globalization. It is facilitating the entry of numerous competitors in the world market (Gunasekaran et al., 2008; Saisse and Wilding, 1997). Severe competition in today's business environment has resulted improvement of fully dynamic and unpredictable processes, thereby, optimizing manufacturing process and performance. Therefore, an industry can withstand against such critical situation by incorporating major revision and restructuring in the existing business strategies execution. There is indeed a need to develop organizational flexibility and responsiveness.

In the contemporary market scenario, customers demand frequently change in a very unpredictable manner. This situation indicates the dynamic nature of customers' demands. Hence, the modern manufacturing organizations should be capable of reconfiguring their existing manufacturing system to suit the dynamic customers' demands (Brown and Bessant, 2003). This condition forces for acquiring the new concept of 'agility' and to sift toward agile manufacturing (AM) paradigm. Agile manufacturing addresses new ways of running companies to react quickly and effectively to ever-changing markets, driven by customer-designed products and services. The foundation for AM is an integration of technologies, people, facilities, information systems and strategies of business process. Agile enterprise in general can provide lower manufacturing costs, increase market share, satisfy customer requirements, facilitate rapid introduction of new products, and eliminate non-value added activities. Therefore, agile manufacturing has aroused great attention all over the world.

Agility is basically a holistic concept, primarily about adaptability, which is achieved through reconfiguration capability. Agility can be defined as the ability of an organization to adapt and react to unexpected or unforeseen changes is critical to achieving and maintaining a competitive advantage (Ganguly et al., 2009). It is all about customer responsiveness and market turbulence and requires specific capabilities that can be achieved using 'lean thinking' (Hoak, 2005).

Agility is mutuality compatible with lean manufacturing, Computer Integrated Manufacturing (CIM), Total Quality Management (TQM), Material Requirement Planning (MRP), Business Process Reengineering (BPR), employee empowerment (Kidd, 1994). The researchers have established that agile manufacturing encompasses lean manufacturing and flexible manufacturing system concepts (Sarkis, 2002). Organizational flexibility is considered as the organization's ability to adjust its internal structures and processes in response to changes in the environment (Reed and Blunsdon, 1998).

However, while embracing the key success factors of agile manufacturing, there are many important questions to be asked concerning a firm's agility level; how and to what degree does the organizational attributes affect companies' business performance; how to measure the agility extent of a company and how to assist in achieving and enhancing existing agility level more effectively (Yusuf et al., 2001; James-Moore, 1997; Sharp et al., 1999). Therefore, agility assessment is viewed an important research agenda in implementing agile manufacturing in practice.

It is indeed a vital issue in strategic planning to determine the degree of agility that an organization currently possesses. It helps the managers to formulate strategic plans and future visions by understanding to what extent an organization is required to be made agile. To achieve an appropriate strategic plan, the business decision mechanism is usually composed of multiple experts (decision-makers) who implement such kinds of decision analysis.

The present study focuses on the development of a conceptual model to evaluate agility index quantitatively, a unique and unprecedented attempt in agility measurement using fuzzy logic to address the ambiguity in agility evaluation. In this evaluation model, the concept of ranking of fuzzy numbers has been explored with index of optimism at the stage of data input for computing the pooled risk bearing attitude of the decision-makers (DM). The influence of human perception (*like fair, conservative and adventurous decision-maker*) on estimated agility index has been examined as well. The application feasibility of the procedural framework has been practically case studied and reported here.

4.3.2 State of Art and Problem Statement

A through literature survey has been carried out from the perspective viewpoint of agility evaluation and related aspects. An enhanced flexible approach based on fuzzy association rule mining was proposed by (Jain et al., 2008) towards evaluating agility in consideration with various attributes such as flexibility, profitability, quality, innovativeness, pro-activity, speed of response, cost and robustness. Vinodh et al. (2010a) presented an agility index measurement model containing twenty criteria incorporated with multi grade fuzzy approach.

Chandna (2008) reported a fuzzy logic based framework incorporating certain operational parameters for the assessment of manufacturing agility. Vinodh et al. (2010c) developed a fuzzy analytic network process (ANP) was proposed for agile concept selection for a manufacturing organization.

Arteta and Giachetti (2004) developed a methodology to estimate extent of agility. The authors concentrated mainly in listing out the changes undertaken to modify the existing system. They suggested a system using *Petri Nets* approach for changing existing practices to achieve enhanced agility. Yang and Li (2002) proposed a procedure to assess agility using fuzzy logic approach. The authors explored a *scale of 2–10* to indicate whether the company possessing agility or not. In order to estimate agility extent in fuzzy context, (Kumar and Motwani, 1995; Lin et al., 2006a, b) defined the concept called *fuzzy agility index (FAI)* to measure agility degree.

Sharifi and Zhang (1999) contributed a scoring model for determining the agility level. Their questionnaire was sent to around 1,000 companies. They reported that the awareness on the agility was 2.8 out of 5 (i.e. 56%). Using this model, it was possible to identify the areas that were either strongly or weakly practiced by an organization to achieve agility. In another paper (Sharifi and Zhang, 2000) contributed two different tools that were encapsulated in agility assessment model. The first tool was made to determine whether a company requires to implement agile programme or not; the second tool facilitated assessment of the agility level. Tsourveloudis (1999) categorized manufacturing agility into four divisions/ infrastructures in order to estimate it. Overall agility was calculated by applying fuzzy logic to individual agility scores in production infrastructure, market infrastructure, people infrastructure and information infrastructure as well.

Yauch (2005) developed a survey based method that calculated agility by measuring turbulence and organizational success. Agility was expressed by the formula:

$$\text{Agility} = \sqrt[3]{\text{S}}\text{x}\,\frac{\text{T}}{5} \tag{4.14}$$

Here, S was the organizational success score and T the turbulence.

Most articles in literature focused on evaluating agility index (AI). Like (Kumar and Motwani, 1995) developed a methodology for assessing time-based competitive advantage of manufacturing firms. Agility measurement model for virtual enterprise was reported by (Goranson, 1999). Hoek et al. (2001) attempted to establish an audit of agility in the supply chain.

Agile manufacturing is a philosophical concept and precise quantitative agility estimation is really difficult in practice. It is believed that agile providers- attribute(s) and agile criterions are logically interconnected and the degree of successful performance of different key agile element, as a whole, contributes to overall agility extent. Most of the agile criterions being subjective; expert opinion is the only choice to capture human perception towards linguistic judgment of criterions' performance level. However, an overall agility estimate is indeed necessary to infer on the present agile practices; to benchmark various agile enterprises and to identify agile barriers which require future attention for improvement. In this context application of fuzzy logic has gained immense popularity. Fuzzy logic is an efficient mathematical tool to correlate linguistic human judgments which are of full of ambiguity, vagueness and incomplete in nature, to a mathematical basis. Agility issues related to agility system modeling, fuzzy agility index evaluation have been addressed in the literature to a considerable extent (Yaghoubi et al., 2011; Garbie, 2011; Kaveh et al., 2011; Radfar, 2011; Somuyiwa et al., 2011; Karuppusami et al.; 2011; Zandi et al., 2011; Tseng and Lin, 2011). However, the effect of decision-making environment and the influence of decision-making attitude (of the decision-makers) have been viewed rarely attempted in the literature. To this end, the present work aims at contributing towards exploration of an agility index evaluation procedural framework to investigative decision makers risk bearing attitude on agility evaluation. Three types of decision-making attitude (viz. neutral, risk-avertor and risk-lover) have been analyzed and compared.

4.3.3 The Agility Evaluation Framework Adopted

The key success factor towards implementing agile manufacturing concept is remaking or rebuilding of manufacture enterprise. According to (Swafford et al., 2006) agility provided the capability to the organization to embed the changes in the marketplace and exploit market opportunities with speed as well as quickness. When the organization is ready to move towards agility, the journey of introducing agile practices into the development existing process begins. A manufacturing sector should essentially possess a set of capabilities responding to changes in the marketplace.

Agile practices are concrete activities and practical techniques that are to be used to develop and manage software projects in a manner consistent with the agile principles. For a truly agile enterprise, it should possess a number of distinguished agile enablers. Wilson and Platts (2010) reported that flexibility could be identified as an important criterion to provide the ability to the firms to deal with uncertainty and unpredicted changes in today's business environments. Flexibility is an ability to process different products and achieve different objectives with the same facilities. Quickness is the ability to carry out tasks and operations in shortest possible time. Agile manufacturing may require some current best practices, lean production concepts, technologies and taken-for-granted assumptions to be re-evaluated, modified or even abandoned. An agile manufacturing system shifts quickly among product models or between product-lines, ideally in real-time response to customer demand (Yusuf et al., 1999), using a toolbox of well-known techniques and methods such as lean manufacturing, Total Quality Management (TQM) or Business Process Engineering. It addresses a company's organizational structure, the impact of people and information, partnerships with other organizations.

It is, therefore, an important problem for evaluating enterprise agility level of and to determine whether an enterprise is fit for survival against market competition successfully. So organizations must seek ways to adopt agile practices and determine the degree of agility they can gain (Elssamadisy, 2006). For agility assessment, in order to determine agile potentials, some measurement index or scale is indeed necessary to enable agility assessment of an entity. The agile practices and concepts are foundational to the agile measurement index. The extent to which agile practices and concepts can be adopted determines the agility of an ongoing process. Extensive literature review on various agile models and related evaluation platform; an integrated model for agility appraisement system has been designed and adopted in the present study which consists of three level agile indices as furnished in (Table 4.28). The model comprises three levels of agility. *Level 1* consists of five agile capabilities/ enablers (providers); *Level 2* consists of thirteen agile attributes and *Level 3* consists of a total of sixty five agile criterions.

The aforesaid model has been case studied in an Indian famous automobile part manufacturing industry at eastern India. Agile scenario of the said industry has been analyzed and interpreted from managerial viewpoint. Agility evaluation procedural hierarchy and its implication while capturing decision-makers different risk bearing attitude have been illustrated in later sections.

4.3.4 Procedural Hierarchy

Company's agility practices are the key success indicators that ensure required potential strength and competitiveness to respond appropriately towards frequent business changes. Therefore, agility practices/ agility culture must provide means for agility measurement for a particular company. The agility index can be defined as combination of agile practices intensity levels. This means to what extent various agile practices are being performed appropriately. The fuzzy agility index evaluation system is a hierarchical model; it encompasses multiple fuzzy comprehensive evaluation methodologies to be utilized. The computation is to be started from lower layer (agile criterions) to the middle layer (agile attributes); then finally to top layer (agile capabilities/providers) to acquire required agility index.

The concept of hierarchical structure analysis with three distinct phases has been adopted in the present research. The first part is to develop an agile framework; secondly, to compute the agility index in fuzzy context; the third part is to analyze pooled risk bearing attitude of decision-makers as described in later sections.

Step 1: By utilizing the knowledge acquired from literature review, a conceptual agility index evaluation framework has been developed by analyzing industrial environment, competitive market, customers' requirement and experts' opinion through a questionnaires survey (shown in Table 4.28). It has been designed as a *three-level* hierarchical model. The main objective i.e. agility, influenced by some agile enablers/providers, that have been placed at the highest level of the hierarchy. The main objective has been divided into five dimensions: organization management agility, product design agility, processing manufacture agility, partnership formation capability and integration of information system. The second level of hierarchy includes thirteen decision domains (attributes); and the third level consists of sixty five agile criterions.

Step 2: A committee of decision-makers is to be formed. Suppose there is a committee of n decision-makers $\left(D_1, D_2, ..., D_n\right)\big|_{i=1,2,...,n.}$ who are responsible for assessing the agility index under k agile practices $\left(C_1, C_2, ..., C_k\right)\big|_{j=1,2,...,k}$ for a particular manufacturing industry.

Step 3: A linguistic scale for appropriateness ratings and importance weights of different agile metrics is to be wisely chosen. In order to assess the performance ratings of various agile practices, the linguistic variable set ***S = {Very Good (VG), Good (G), Fair (F),***

Poor (P) and Very Poor (VP)} can be used in (0-10) point scale. In order to assess priority weights of corresponding agile practices the linguistic variable set ***W = {Very High (VH), High (H), Medium (M), Low (L), Very Low (VL)}*** may be used in (0-1) point scale.

Step 4: Expert opinions are to be drawn from the decision-makers for appropriate ratings and importance weights of different agile metrics. The evaluation committee has to compute aggregated fuzzy weight W_{ij} and W_i. Here W_{ij} is the aggregated fuzzy priority weight of j_{th} agile criteria (which is under i_{th} attribute); W_i be the weight of i_{th} agile attribute.

Step 5: The agility index of the organization is represented by I. It is the product of the overall assessment factor (R) and the overall weight (W). The equation for agility index is shown as follows:

$$I = W \otimes R \tag{4.15}$$

The agility index assessment is done at three stages: as primary assessment, secondary and tertiary assessment. The calculation is performed in a hierarchical order from third level to second level and finally at first level i.e. to obtain overall agility index. Then the final score F_i fuzzy appropriateness index for decision-makers D_i can be obtained.

Step 6: Let $S_{ij} = (q_{ij}, o_{ij}, p_{ij})$ and $W_{ij} = (c_{ij}, a_{ij}, b_{ij})$. F_i can be obtained by $F_i \cong (Y_i, Q_i, Z_i)$. The total index of rating attitude β which reflects the decision maker's risk bearing attitude with evaluation data of individuals can be obtained by (Chang, 1994):

$$\beta = [\sum_{i=1}^{n}\sum_{j=1}^{k}(a_{ij} - c_{ij}) + \sum_{i=1}^{n}\sum_{j=1}^{k}(o_{ij} - q_{ij})/(p_{ij} - q_{ij})]/(k*n + k*n)_{input} \tag{4.16}$$

The ranking values $U_T(F_i)$ can be approximately obtained by Eq. 4.17,

$$U_T(F_i) \cong \beta[(z_i - x_1)/(x_2 - x_1 - Q_i + Z_i)] + (1-\beta)[1-(x_2 - Y_i)/(x_2 - x_1 + Q_i - Y_i)] \tag{4.17}$$

For $i = 1, 2, ..., n;\ X_1 = \min\{Y_1, Y_2, ..., Y_n\}$ and $X_2 = \max\{Z_1, Z_2, ..., Z_n\}$

Step 7: The ranking order for fuzzy appropriate indices for different set of decision makers is found out.

Step 8: Thus, the overall agile index is computed. The assessment is carried out in four grades: Value (0.85-1) represents *very agile*, (0.6-0.85) represents *agile*; (0.35-0.6) *moderately agile*, and (0.1-0.35) indicates *merely agile*.

4.3.5 Case Study

The proposed model has been verified in an automobile part manufacturing industry located at eastern part of India. A committee of four decision makers (D_1, D_2, D_3, D_4) has been constructed. Three case studies have been critically examined and analyzed as well. Through a questionnaire survey, expert opinions i.e. subjective judgment of human perception have been captured for all agile practices highlighted in the model. The linguistic scale for fuzzy appropriateness rating and weights of corresponding agile practices has been determined as shown in (Appendix: Tables 4.29-4.30) for $\beta \approx 0.5$; (Appendix: Tables 4.36-4.37) for $\beta \approx 0.2$ and (Appendix: Tables 4.43-4.44) for $\beta \approx 0.9$. The linguistic representation for fuzzy appropriateness rating and weights of corresponding agile practices has been determined as shown in (Appendix: Tables 4.31 and Tables 4.32-4.34) for $\beta \approx 0.5$; (Appendix: Table 4.38 and Tables 4.39-4.41) for $\beta \approx 0.2$ and (Appendix: Table 4.45 and Tables 4.46-4.48) for $\beta \approx 0.9$. The agility assessment has been carried out according to Eq. (4.15) at each level of the agility; starting from the third level. The final result has been presented in later section.

Table 4.28: Proposed agility appraisement model			
Sl. No.	Level 1 index	Level 2 index	Level 3 index
1.	Organization management agility (I_1)	Agility in institutional framework (I_{11})	Existence of a well-defined system architecture to promote agility (I_{111})
			Establishing a physically distributed manufacturing architecture precisely in a stable state (I_{112})
			Ability to rapidly set up the entire organization adaptable to new method of operation (I_{113})
			Frequency of enterprise modeling (I_{114})
			Adaptability of best practices in other organizations by benchmarking (I_{115})
			Application of business process reengineering (BPR) for reinventing and reengineering the organization (I_{116})
			Good housekeeping practices (I_{117})
		Team building agility (I_{12})	Speed of the team building (I_{121})
			Formation of team across company borders (I_{122})
			Use of interdisciplinary teams by organizing themselves to take the advantages of market opportunities(I_{123})
			Empowerment of personnel to resolve customer and process related problems (I_{124})
		Production organizing agility (I_{13})	Adoption of Concurrent Engineering (CE) (I_{131})
			Identification of market for new products (I_{132})
			Degree of innovation and new product development (NPD) techniques that calls for uniqueness and novelty in the product (I_{133})
			Degree of automation applied to manufacturing (I_{134})
			Degree of automation in inspection systems (I_{135})
2.	Product Design Agility (I_2)	Product design flexibility (I_{21})	Management's interest towards evolving new product models (I_{211})
			Extent of inculcation of innovation into product design(I_{212})
			Degree of Recycling orientation during product design(I_{213})
			The serating degree of the product (I_{214})
			Degree of standardization and commonality (I_{215})
			Speed at which suppliers are being developed for new products (I_{216})
			Similarity of the product structure (I_{217})

			Preparedness of the management to invest on latest design techniques like RP and CAD/CAM (I_{218})
			Products incorporated with modular design (I_{219})
		Customer demand information agility (I_{22})	Swiftness in obtaining demand information (I_{221})
			Extent of customer satisfaction orientation (I_{222})
			The proportion of information processing time in product period(I_{223})
		Product Design Speed(I_{23})	Time for product development cycle time (I_{231})
			Design selection that minimizes the no of parts (I_{232})
			Design lead time (I_{233})
3.	Processing manufacture agility (I_3)	Re-configurability of manufacturing system (I_{31})	Capability of packaging the integrated unit in a modular fashion (I_{311})
			Supplement tool displacement (I_{312})
			Displacement compatibility(I_{313})
			Displacement of process variety(I_{314})
			Design for manufacturing and assembly(I_{315})
		Speed of manufacturing (I_{32})	Period of both inter-lot and in-lot set up time(I_{321})
			Speed of material handling systems(I_{322})
			Leadership in the use of current technology(I_{323})
			The overall period of product manufacture(I_{324})
			The proportion of manufacturer period in products period (I_{325})
		Manufacturing flexibility (I_{33})	Flexible material handling equipment (I_{331})
			The universal degree of equipment (I_{332})
			The scalable degree of equipment (I_{333})
			Flexibility of equipment (I_{334})
4.	Partnership formation capability (I_4)	Inter-organization co-ordination (I_{41})	Degree of enterprise integration (I_{411})
			Degree of cooperation with other enterprise (I_{412})
			Reliable network of suppliers (I_{413})
			Adoption of SCM concepts for enhancing the outsourcing efficiency (I_{414})
		Cross-border Collaboration (I_{42})	Strategic relationship with customers (I_{421})
			Speed of development of products jointly with other companies (I_{422})

			Trust based relationship (*I_{423}*)
			Speed of partnership formation (*I_{424}*)
			Formation of Virtual manufacturing enterprise(VME) (*I_{425}*)
5.	Integration of Information system (I_5)	Information management agility (I_{51})	Interoperability and Networking (*I_{511}*)
			Ability to exchange information (*I_{512}*)
			Utilizing artificial intelligence(AI) with computer aided design (*I_{513}*)
			Correctness and accuracy of data (*I_{514}*)
			Maintenance information system (*I_{515}*)
			Companywide integration of information system (I_{516})
			IT application to eliminate paper work (I_{517})
			Adoption of multimedia technology (I_{518})
		Speed of information (I_{52})	Information and network utilization rate (*I_{521}*)
			Utilization of electronic data exchange system (EDI) (*I_{522}*)

Results of Case Study 1

Overall weight:

$$W = [(0.6000, 0.8000, 1.0000) \quad (0.5500, 0.7750, 1.0000) \quad (0.6000, 0.8000, 1.0000) \quad (0.6000, 0.8000, 1.0000) \quad (0.6500, 0.8250, 1.0000)]$$

Overall assessment vector:

$$R = \begin{vmatrix} (15.5000, 48.0295, 109.5687) & (15.9625, 46.3133, 101.5587) & (16.8500, 50.4450, 112.0438) & (14.7900, 45.9123, 104.9563) \\ (7.3200, 31.7317, 82.0119) & (11.6525, 40.0027, 95.1950) & (15.9525 \quad 49.3982 \quad 112.1625) & (10.3875, 36.2341, 87.2706) \\ (14.5763, 47.3258, 109.8925) & (12.7988, 44.5702, 106.7125) & (12.5287, 42.9291, 102.1681) & (12.6563, 41.0994, 95.5269) \\ (10.5075, 33.9059, 78.6050) & (11.2325, 34.5973, 78.1656) & (10.5525, 33.3043, 76.2463) & (10.3825, 32.9273, 75.5988) \\ (14.0775, 39.3311, 84.3500) & (17.6925, 45.1789, 92.2000) & (16.5375, 44.0261, 92.2000) & (17.3325, 43.3739, 87.3500) \end{vmatrix}$$

$$I = \left| \, (37.5266, 160.4492, 464.4281) \quad (41.9052, 168.6593, 473.8319) \quad (43.4820, 175.9479, 494.8206) \quad (39.6765, 159.8162, 450.7025) \right|$$

The total index of rating attitude β taking (Eq. 4.16) has been find out to reflect the decision makers risk bearing attitude.

$$\beta = 0.5169$$

The ranking value for four decision makers has been find out according to the (Eq. 4.17) and shown in (Appendix: Table 4.35).

$U_T(F_1) = 0.3922$, $U_T(F_2) = 0.4042$, $U_T(F_3) = 0.4179$ $U_T(F_4) = 0.3878$

The overall agility index is 0.4005, which belongs to the range (0.35-0.6) i.e. moderately agile.

Results of Case study 2

Overall weight:

$$W = [(0.6000,0.8000,1.0000) \quad (0.5500,0.7750,1.0000) \quad (0.6000,0.8000,1.0000) \quad (0.6000,0.8000,1.0000) \quad (0.6500,0.8250,1.0000)]$$

Overall assessment vector:

$$R = \begin{vmatrix} (15.5000,48.0295,109.5687) & (15.9625,46.3133,101.5587) & (16.8500,50.4450,112.0438) & (14.7900,45.9123,104.9563) \\ (7.3200,31.7317,82.0119) & (11.6525,40.0027,95.1950) & (15.9525 \quad 49.3982 \quad 112.1625) & (10.3875,36.2341,87.2706) \\ (14.5763,47.3258,109.8925) & (12.7988,44.5702,106.7125) & (12.5287,42.9291,102.1681) & (12.6563,41.0994,95.5269) \\ (10.5075,33.9059,78.6050) & (11.2325,34.5973,78.1656) & (10.5525,33.3043,76.2463) & (10.3825,32.9273,75.5988) \\ (14.0775,39.3311,84.3500) & (17.6925,45.1789,92.2000) & (16.5375,44.0261,92.2000) & (17.3325,43.3739,87.3500) \end{vmatrix}$$

$$I = \left| (37.5266,160.4492,464.4281) \quad (41.9052,168.6593,473.8319) \quad (43.4820,175.9479,494.8206) \quad (39.6765,159.8162,450.7025) \right|$$

The total index of rating attitude β taking (Eq. 4.16) has been find out to reflect the decision makers risk bearing attitude.

$$\beta = 0.2073$$

The ranking value for four decision makers has been find out according to the (Eq. 4.17) and shown in (Appendix: Table 4.42).

$U_T(F_1) = 0.1396$, $U_T(F_2) = 0.2122$, $U_T(F_3) = 0.2001$, $U_T(F_4) = 0.1628$

The overall agility index is 0.1786, which belongs to the range (0.1-0.35) i.e. merely agile.

Results of Case Study 3

Overall weight:

$$W = [(0.6000, 0.8000, 1.0000) \quad (0.5500, 0.7750, 1.0000) \quad (0.6000, 0.8000, 1.0000) \quad (0.6000, 0.8000, 1.0000) \quad (0.6500, 0.8250, 1.0000)]$$

Overall assessment vector

$$R = \begin{vmatrix} (15.5000, 48.0295, 109.5687) & (15.9625, 46.3133, 101.5587) & (16.8500, 50.4450, 112.0438) & (14.7900, 45.9123, 104.9563) \\ (7.3200, 31.7317, 82.0119) & (11.6525, 40.0027, 95.1950) & (15.9525 \quad 49.3982 \quad 112.1625) & (10.3875, 36.2341, 87.2706) \\ (14.5763, 47.3258, 109.8925) & (12.7988, 44.5702, 106.7125) & (12.5287, 42.9291, 102.1681) & (12.6563, 41.0994, 95.5269) \\ (10.5075, 33.9059, 78.6050) & (11.2325, 34.5973, 78.1656) & (10.5525, 33.3043, 76.2463) & (10.3825, 32.9273, 75.5988) \\ (14.0775, 39.3311, 84.3500) & (17.6925, 45.1789, 92.2000) & (16.5375, 44.0261, 92.2000) & (17.3325, 43.3739, 87.3500) \end{vmatrix}$$

$$I = \left| (37.5266, 160.4492, 464.4281) \quad (41.9052, 168.6593, 473.8319) \quad (43.4820, 175.9479, 494.8206) \quad (39.6765, 159.8162, 450.7025) \right|$$

The total index of rating attitude β taking (Eq. 4.16) has been find out to reflect the decision makers risk bearing attitude.

$$\beta = 0.9297$$

The ranking value for four decision makers has been find out according to the (Eq. 4.17) shown in (Appendix: Table 4.49).

$U_T(F_1)$ =0 .8171, $U_T(F_2)$ = 0.7881, $U_T(F_3)$ = 0.7462, $U_T(F_4)$ = 0.8001

The overall agility index is 0.7878, which belongs to the range (0.6-0.85) i.e. very agile.

Aforesaid case studies reflect the effect of variation of decision-makers risk bearing attitude towards estimating overall agility index and to dictate the present state of organizational agility level. For a conservative DMs group, the enterprise agility level has been estimated as '*merely agile*' as the DMs are risk avertor. Fair or neutral decision-making group has analyzed the same enterprise agility level as '*moderately agile*'; while for an adventurous decision-making group, the organizational agility level has been evaluated as '*very agile*' as the decision-makers have been driven by their risk-loving attitude.

For **Case Study 1:** The overall agility index obtained is 0.4005, which belongs to the range (0.35-0.6) i.e. **moderately agile**. For **Case Study 2:** The overall agility index is 0.1786, which belongs to the range (0.1-0.35) i.e. **merely agile**. For **Case Study 3:** The overall agility index is 0.7878, which belongs to the range (0.6-0.85) i.e. **very agile**.

It has been found that the fuzzy value of organizational agility degree varies with the type of decision-making group chosen. Estimation of the same organizational agility level provides different results for different decision-making group depending on individuals risk bearing attitude. Therefore, it is an important managerial decision to select the particular decision-making group to compute and analyze agility level for a particular organization. In case of benchmarking of various agile enterprises the decision-making group bearing same attitude should be utilized.

4.3.6 Managerial Implications

Aforesaid study reveals that selection and composition of the decision-making team (decision-makers) bears significant impact on the decision outcome. Decision making environment as well as decision-makers attitude also influences the said decision outcome. It is therefore, indeed necessary to assess the extent of influence of decision-makers' risk bearing attitude, towards agility estimation. In the present study, it has been revealed that change in decision-makers' attitude results consideration change in existing agility level measured in the predefined agility scale. Management should decide the type of decision-makers' risk bearing attitude to be considered in the decision-making process. The same type must be chosen towards agility appraisement for other enterprises for the purpose of comparison (from agility point of view), benchmarking and selection of the best agile enterprise.

4.3.7 Concluding Remarks

Agile Manufacturing is an operational strategy which emphasizes on inducing speediness and flexibility in a make-to-order or configure-to-order production process with minimal changeover time and interruptions. Agile Manufacturing products are definitely capable of competing directly with standard products, providing a customer with configurable opportunity to specialize a product. Agile system modeling and corresponding agility assessment forum have been attempted and well documented in literature while the influence of decision-makers risk bearing attitude and the effect of decision-making environment on estimating overall agility degree has rarely been attempted by the pioneers. In this context, the present study explores an extended agility model in a specific organization's hierarchy and reflects how decision-making attitude alters snapshot of organizational agility scenario.

Compared to the existing literature, the contribution of the present research has been highlighted below.

1. Development of fuzzy based integrated agility appraisement module.
2. Incorporation of variation of decision-makers risk bearing attitude in the said appraisement module.
3. The research reflects considerable effect of variation of decision-makers attitude towards agility estimation.

CHAPTER 5

SUPPLIER EVALUATION AND SELECTION IN AGILE SUPPLY CHAIN

5.1 Supplier Evaluation in ASC using Fuzzy Logic

5.1.1 Overview

In today's turbulent business environment it is evident that a business must be agile as well as efficient. Supply chains can help in achieving this through enhancing the ability to respond quickly to customer demand and by reducing operating costs. One of the biggest challenges facing organizations today is the need to respond to ever increasing levels of volatility in demand. Agility is defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer designed high-quality, high-performance, products and services (Chandna (Kharbanda), 2008). Agile supply chains need to be highly flexible in order to reconfigure quickly in response to changes in their environment. Supplier lies in the first node of the supply chain. Rational supplier evaluation (and selection) is really important to the entire supply chain's agility. An effective supplier selection process is indeed essential for this. To this end, present work highlights an integrated performance appraisement module towards suppliers' evaluation in agile supply chains. Apart from evaluating suppliers' overall performance index; the study has been extended to identify ill-performing areas in which suppliers should prosper in future. Fuzzy logic has been adapted here to facilitate the said appraisement modelling.

5.1.2 Importance and Issues of Supplier Evaluation in Agile Supply Chain

Agile manufacturing is a concept focused on meeting customers' needs while maintaining high standards of product quality and controlling the overall costs involved in the production process. This approach is geared towards companies working in a highly competitive environment, where small variations in performance and product delivery can make a remarkable difference in the long term to a company's survival and reputation among the consumers.
[Source: *http://www.wisegeek.com/what-is-agile-manufacturing.htm*]
Companies aiming to utilize an agile manufacturing philosophy must maintain very strong networks with suppliers and related companies, along with numerous cooperative teams which work within the company to deliver products effectively. They should retool facilities quickly, negotiate new agreements with suppliers and other partners in response to abruptly changing market forces, and take necessary steps to meet customer unpredicted demands. This means that the company can increase production with a high consumer demand, as well as

redesign/reconfigure products to respond to issues which have emerged on the open marketplace.

In recent era of globalization, market has become turbulent. Markets can change very quickly, especially in the global economy. A company which cannot adapt quickly to change may lag behind. The goal of agile manufacturing is to take competitive advantage, which allows it to continue innovating and introducing new products, because it is financially stable and it has a strong consumer support base.

Kaveh and Mohammad (2012) developed a three-stage fuzzy Data Envelopment Analysis (DEA) approach to measure performance of a serial process including JIT practices, agility indices, and goals in supply chains.

Agile supply chains need to be highly flexible in order to reconfigure quickly in response to changes in their environment. An effective supplier selection process is essential for this (Luo et al., 2009).

5.1.3 State of Art and Problem Formulation

Supplier selection is basically a Multi-Criteria Decision Making (MCDM) problem involving qualitative as well as quantitative criteria. Existing literature is rich in dealing with such MCDM problem related to suppliers' evaluation in general context. Agile suppliers' selection (or suppliers' selection cum evaluation) in agile supply chain are now being viewed as a special area of focus.

Das and Barman (2010) developed a two-stage decision framework for evaluating suppliers of high-value and critical items with reference to a heavy engineering organization by employing the Analytic Hierarchy Process (AHP). The first stage involved examining the qualifying criteria of the items on quality, while the second stage was concerned with identifying all other relevant attributes, including quality concerning high-value and critical items applicable to the organization under study, and with finding out the relative importance of the same. Raut et al. (2011) proposed a combined MCDM methodology: Fuzzy analytic hierarchy process (AHP) and linear programming (LP) utilized for assigning weights of the criteria for supplier selection and TOPSIS (technique for order preference by similarity to ideal solution) was used to determine the most suitable alternative using these criteria weights.

Sandeep et al., (2011) used fuzzy strategy-aligned simple multi-attributes rating technique (SMART) for supplier selection process. Mahdiloo et al. (2012) focused on the DEA based supplier selection problem with volume discount offerings. Mishra et al. (2012) applied VIKOR method adopted in a fuzzy environment to assess multi-criteria attributes on suppliers' performance and to select the best supplier among a group of alternative suppliers. Individual attribute weights as well as supplier's attribute measures were expressed in terms of linguistic fuzzy numbers, then a hierarchy MADM model based on fuzzy sets theory and VIKOR method was applied to deal with such a supplier selection problem.

As found in literature, several decision-making tools have been applied to facilitate suppliers' selection problem. Some relevant works carried out especially in the suppliers' selection in agile supply chain have been documented below.

Lou et al., (2002) reported on application of AHP/DEA method for the vendor selection in the agile supply chain. Baramichai (2007) and Baramichai et al. (2007) proposed a comprehensive, modular decision support system, which included tools, models, and framework to assist companies in making three key purchasing decisions, the supplier-buyer relationship establishment, the supplier performance evaluation, and the supplier selection and order allocation. The author introduced the QFD-based model, Agile Supply Chain Transformation Matrix (ASCTM), for determining appropriate strategy and approaches for supply chain configuration and supplier-buyer relationship establishment; the comprehensive framework consisting of tools, metrics, and model structures for evaluating supplier's agile performance; and the Stochastic Supplier and Order Allocation Portfolio model (S-SOAP) for determining the purchasing decision related to supplier selection, contract establishment, and order allocation assignment under uncertainty.

Wu and Barnes (2008) applied neural network-based supplier evaluation model on Agile Supply Chain-based Supplier Selection and Evaluation. Hasan et al. (2008) applied Analytical Network Process (ANP) and Data Envelopment Analysis (DEA) in a multi-phased supplier selection approach in an agile manufacturing environment. Initially, ANP was executed to appraise suppliers on their qualitative benefits, generating quantitative data from these qualitative dimensions. Secondly, DEA was used to synthesize the data to arrive at a ranking of the suppliers. Ren et al. (2009) proposed a decision-support framework for the evaluation and selection of business partners in order to help the industry form agile supply chains.

Wu and Barnes (2009) presented a model designed to provide feedback and continuous improvement during the process of supplier selection in agile supply chains (ASCs). The model was made seeking to capitalize on the increased application of the supplier section process by applying principles of continuous improvement and organizational learning. Its aim was to support organizational decision-makers in their efforts to optimize the performance of the supply chain by ensuring that only the most appropriate suppliers are selected at all times. Luo et al.

(2009) developed a model to overcome the information-processing difficulties inherent in screening a large number of potential suppliers in agile supply chains. Based on radial basis function artificial neural network (RBF-ANN), the model enabled potential suppliers to be assessed against multiple criteria using both quantitative and qualitative measures. Fang et al. (2010) analysed the standard for evaluating jet fuel supplier and constructs an evaluation index system for jet fuel supplier evaluation in an agile supply chain. Wu and Barnes (2010) formulated partner selection criteria for agile supply chains using Dempster–Shafer belief acceptability optimization approach.

Ghahremanloo and Tarokh (2011) contributed to the discussion on agility in SCM and provided a novel focus on the integration in ASC. This research proposed a multi-agent-based model of ASCM that was capable of supporting the resource coordination between agents through a combinatorial action mechanism as well as selecting agile supplier. This model was validated by means of fuzzy multi-objective linear programming. Wu and Barnes (2012) presented a four-phase dynamic feedback model for supply partner selection in agile supply chains (ASCs). The model considered both quantitative and qualitative techniques, including the Dempster-Shafer and optimization theories, radial basis function artificial neural networks (RBF-ANN), analytic network process-mixed integer multi-objective programming (ANP-MIMOP), Kraljic's supplier classification matrix and principles of continuous improvement.

In today's competitive global markets, selection of a potential supplier plays an important role to cut production costs as well as material costs of the company. This leads to successful survival and sustainability in competitive marketplace. The current business environment has imposed competitive pressures on suppliers to match the needs of buyer(s) in terms of quantity, quality, product mix, cost, time and place of delivery, and other performance measures. The focus on competitive supply chains and extended enterprises requires the adoption of agile manufacturing practices requiring their suppliers to have agile attributes (Hasan et al., 2008). In this context, an evaluation and selection of an appropriate supplier has become an important part of agile supply chain management. The nature of supplier selection process is a complex Multi-Attribute Group Decision Making (MAGDM) problem which deals with both quantitative and qualitative factors may be conflicting in nature as well as contain incomplete and uncertain information. In order to solve such kind of MAGDM problems, development of an effective supplier selection module is evidently desirable.

This study establishes a fuzzy based structured evaluation module towards investigating the suitability of suppliers for an organization competing on agile manufacturing characteristics. Quantitative and qualitative factors have been explored to appraise supplier's performance to fit within an organization's agility practices. The proposed evaluation module has been extended towards identifying ill-performing areas in which a particular supplier seeks future improvement.

5.1.4 Proposed Fuzzy Based Supplier Evaluation Module

A fuzzy based supplier evaluation module in agile manufacturing proposed in this work has been present below. General Hierarchy Criteria (GHC) for supplier selection in ASC, adapted in here has been shown in Table 5.1. It consists of three-level index system; 1st level aims at achieving the target to evaluate suppliers' overall appraisement index. 2nd level comprises of various selection criterions and the 3rd level illustrates sub-criterions under different 2nd level criteria. Production and logistics management, Partnership management, Financial capability, Technology and knowledge management, Marketing capability, Industrial and organizational competiveness and Human resource management have been shown as 2nd level criteria followed by various sub-criteria in 3rd level. Procedural steps for suppliers' evaluation have been presented as follows:

1. Selection of linguistic variables towards assigning criteria weights (both at 2nd and 3rd level) and appropriateness rating (performance extent) corresponding to each sub-criterion at 3rd level.
2. Collection of expert opinion (subjective judgment) from a selected decision-making group in order to express priority weight as well as appropriate rating against each of the selection criterion.
3. Representing decision-makers' linguistic judgments using appropriate fuzzy numbers set.
4. Use of fuzzy operational rules towards estimating aggregated weight as well as aggregated rating (pulled opinion of the decision-makers) for each of the selection criterion.
5. Calculation of computed performance rating of 2nd level criteria and finally overall suppliers' performance index, called Fuzzy Performance Index (FPI) i.e. targeted goal at the 1st level.

Appropriateness rating U_i for i_{th} 2nd level criterion has been computed as follows:

$$U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \quad (5.1)$$

In this expression (Eq. 5.1) U_{ij} is denoted as the aggregated fuzzy appropriateness rating against j_{th} sub-criterion (at 3rd level) which is under i_{th} main criterion in 1st level. w_{ij} is the aggregated fuzzy weight against j_{th} sub-criterion (at 3rd level) which is under i_{th} main criterion in 2nd level.

The Fuzzy Performance Index (FPI) at 1st level has been computed as:

$$U(FPI) = \frac{\sum U_i \otimes w_i}{\sum w_i} \qquad (5.2)$$

In this expression (Eq. 5.2) U_i is denoted as the computed fuzzy appropriateness rating (obtained using Eq. 5.1) against i_{th} main criterion in 2nd level. w_i is the aggregated fuzzy priority weight against i_{th} main criterion in 1st level.

6. Investigation for identifying ill-performing areas those seek for future improvement.

5.1.5 Empirical Research

Empirical data has been explored to investigate application feasibility of the proposed appraisement platform. Initially a decision-making group has been assumed constructed by the top management of an organization consisting of a number of decision-makers. After critical investigation and scrutiny each decision-maker has been instructed to explore the linguistic scale (Table 5.2) towards assignment of priority weight and appropriateness rating against each selection criterion. Tables 5.3-5.4 (furnished in Appendix) provides decision-makers' subjective judgment in linguistic terms in relation to weight assignment. Appropriateness rating (subjective score as given by the decision-makers) for 3rd level sub-criterions has been furnished in (Appendix: Table 5.5). These linguistic expressions (human judgment) have been converted into appropriate generalized trapezoidal fuzzy numbers as presented in Table 5.2. The method of *simple average* has been used to obtain aggregated priority weights of 2nd level criteria and 3rd level sub-criteria (Appendix: Tables 5.6-5.7). Similarly, aggregated fuzzy appropriateness rating has been obtained for 3rd level sub-criteria and shown in (Appendix: Table 5.6). Computed fuzzy performance ratings for 2nd level main criterions have thus been obtained by using Eq. 5.1 (Appendix: Table 5.7). Finally, Eq. 5.2 has been used to obtain overall FPI.

The FPI thus obtained as: (0.4419, 0.6059, 0.8782, 1.2112).

The FPI may be compared with a predefined performance estimation scale set by the management to check the current performance practices for the suppliers'. Thus, ill-performing areas may be sorted out and in future, the said supplier should think of feasible means towards improvement of its overall performance degree.

The concept of '*Ranking of fuzzy numbers with maximizing set and minimizing set*' has been adapted here to indentify ill-performing areas of suppliers' performance. 3rd level sub criteria have been ranked based on their individual aggregated performance rating (Table 5.8). In this computation, three types of decision-makers risk bearing attitude [$(\alpha = 0; \alpha = 0.5, \alpha = 1)$ i.e. *pessimistic, moderate and optimistic decision-maker*] have been explored to estimate overall utility score against each 3rd level sub-criterions. The sub-criterion with higher utility degree is assumed to have top ranking order. Thus, supplier selection sub-criterions have been ranked accordingly.

The study also utilizes the concept of '*Degree of Similarity*' *between two fuzzy numbers* (Chen 1996; Heish and Chen, 1999; Chen and Chen, 2003; Yong et al., 2004; Chen, 2006; Sridevi and Nadarajan, 2009) for 3rd level sub-criteria ranking. In this computation, individual aggregated performance rating of 3rd level sub-criterion has been compared with the overall 'FPI' in order to compute degree of similarity between them.

The degree of similarity between individual aggregated criterion performance ratings with overall FPI has been computed and furnished in Table 5.9. Higher value of *DOS* yields top ranking order for the particular sub-criterion. In other words, it can be inferred that the particular 3rd level sub-criterion whose DOS value is high, contributes more to the overall '*Fuzzy Performance Index*'.

Based on the concept of *DOS*, supplier' selection sub-criterions have been ranked and compared with the results obtained, thereof using the concept of '*total utility degree*'. Thus, it can be concluded that '*Degree of Similarity*' concept may be one of the feasible means towards identifying ill-performing suppliers' selection sub-criteria.

5.1.6 Managerial Implications

The objective of this reporting is to develop an efficient decision support system to help industries to improve their supply agility by focusing on the suppliers' evaluation and selection processes. Because, under today's volatile business environment, companies are reaching the point where they need to be more agile-intelligent, fast, flexible, and responsive to changes (Baramichai, 2007). Literature reveals that considerable amount of work has been carried out by pioneer researchers towards supplier selection cum evaluation in the context of Agile Supply Chain Management (ASCM). Most of the appraisement indices (supplier selection criteria) being subjective in nature, fuzzy analysis of expert opinion is indeed logical as well as scientific. Apart from performance assessment, another important aspect is the need for identifying weakly performing areas. It has been found that in analyzing agility index in fuzzy context, previous researchers used the concept of '*maximizing set and minimizing set*' (for comparing a pair of fuzzy numbers) based on their individual utility values. The purpose was to identify agile barriers [Lin et al., 2006a, b; Vinodh et al., 2010a, b, c, d]. Thus, agile criterions were ranked accordingly. It is felt that the same concept can also be applied to identify areas in which supplier's performance is unsatisfactory. It is also felt that apart from utilizing the concept of fuzzy numbers ranking using '*maximizing set and minimizing set*'; the concept of '*Degree of Similarity Measure*' (between a pair of fuzzy numbers) may be suitable to sort out various weak areas. Motivated by this, the present work aims at developing a fuzzy integrated overall performance assessment module to estimate an overall supplier's evaluation index (SEI) in ASCM. The work proposes an alternative approach towards identifying ill-performing areas as well. Industries may adopt the proposed appraisement philosophy to select appropriate supplier towards improving overall supply chain agility.

5.1.7 Concluding Remarks

In today's turbulent competitive global market place, supply chain agility has become one of the major concerns for every manufacturing industry, production units and their supply chains. Suppliers play an important role in supply chain management. Appropriate supplier selection through implementing effective appraisement module may enhance overall supply chain agility. In this context, present study proposes a fuzzy induced suppliers' appraisement module and extends towards indentifying ill-performing areas. Apart from estimating suppliers' overall performance index, the work proposes exploration of the concept of '*Degree of Similarity*' *(between two fuzzy numbers)* to identify weak areas that need future improvement to improve overall performance degree.

The contributions of this part of research have been summarized as follows:

1. Development of a fuzzy-based appraisement module towards evaluation as well as selection of appropriate supplier in agile supply chain.
2. Estimation of a unique appraisement index highlighting candidate suppliers' overall performance.
3. The proposed appraisement module helps individual suppliers to identify ill-performing areas which require future improvement.
4. The study proposes the concept of 'Fuzzy Degree of Similarity' as a tool to rank suppliers' performance ratings against individual evaluation criterions.

The research can be extended in the following directions:

1. Benchmarking of individual suppliers' in agile supply chain.
2. To investigate possible means by which suppliers' can improve ill-performing areas.

Table 5.1: General hierarchy criteria (GHC) for supplier evaluation in ASC

1st Level	2nd Level criteria, C_i	3rd Level sub-criteria, $C_{i,j}$
Evaluation index of potential suppliers in ASC, C	Production and logistics management, C_1	Production volume flexibility, $C_{1,1}$ (Sarkar and Mahapatra, 2006)
		Variation in types of products or services, $C_{1,2}$ (Choy et al., 2003)
		Post-sales service and support, $C_{1,3}$ (Choi and Hartley, 1996)
		Order lead time, $C_{1,4}$ (Chung et al., 2005)
		Responsiveness to customer needs, $C_{1,5}$ (Choy et al., 2003)
		Condition of physical facilities, $C_{1,6}$ (Chung et al., 2005)
		Design capability, $C_{1,7}$ (Sarkar and Mahapatra, 2006)
		Cost-reduction capability, $C_{1,8}$ (Yigin et al., 2007)
		Quality philosophy, $C_{1,9}$ (Sarkar and Mahapatra, 2006)
		Delivery capacity and reliability, $C_{1,10}$ (Yigin et al., 2007)
		Distribution network performance and quality, $C_{1,11}$ (Lin and Chen, 2004)
		Quality assurance system, $C_{1,12}$ (Yigin et al., 2007)
		Manufacturing network performance, $C_{1,13}$ (Choi and Hartley, 1996)
		Order fulfillment rate, $C_{1,14}$ (Narasimhan et al., 2006)
		Average defect rate, $C_{1,15}$ (Hajidimitriou and Georgiou, 2002)
		Price/cost ratio, $C_{1,16}$ (Talluri et al., 1999)
		Geographical location, $C_{1,17}$ (Yan et al., 2003)
		Production capabilities, $C_{1,18}$ (Talluri et al., 1999)
		Sophistication of product lines, $C_{1,19}$ (Choy et al., 2003)
		Capabilities to provide quality product/service, $C_{1,20}$ (Lin et al., 2006a, b)
		Quality stability, $C_{1,21}$ (Mikhailov, 2002)
		Volatility of product mix, $C_{1,22}$ (Talluri et al., 1999)
		Transportation cost, $C_{1,23}$ (Narasimhan et al., 2006)
		Service level, $C_{1,24}$ (Choy et al., 2002)
		Consistent conformance to specifications, $C_{1,25}$ (Choi and Hartley, 1996)
		Warranty period, $C_{1,26}$ (Xia and Wu, 2007)
	Partnership management, C_2	Government relationships, $C_{2,1}$ (Harvey and Lusch, 1995)
		Information available on supplier, $C_{2,2}$ (Gencer and Gurpinar, 2007)
		Risk of failure cooperation, $C_{2,3}$ (Ip et al., 2003)
		Easy communication, $C_{2,4}$ (Ngai et al., 2004)
		Willing to invest in sales training, $C_{2,5}$ (Cavusgil et al., 1995)
		Compatible management styles, $C_{2,6}$ (Hajidimitriou and Georgiou, 2002)

		Industrial experience, $C_{2,7}$ (Luo, 1998)
		Cost to integration, $C_{2,8}$ (Ip et al., 2003)
		Alliance experience, $C_{2,9}$ (Harvey and Lusch, 1995)
		Willingness to resolve conflict, $C_{2,10}$ (Choi and Hartley, 1996)
		Financial institution relationship, $C_{2,11}$ (Harvey and Lusch, 1995)
		Closeness to past relationship, $C_{2,12}$ (Choi and Hartley, 1996)
		Data information, $C_{2,13}$ (Ngai et al., 2004)
		Relationship building flexibility, $C_{2,14}$ (Lin and Chen, 2004)
		Power relative to potential partner, $C_{2,15}$ (Harvey and Lusch, 1995)
		Company's reputation to integrity, $C_{2,16}$ (Sarkar and Mahapatra, 2006)
		The stability of the joint venture, $C_{2,17}$ (Lorange et al., 1992)
		Time needed to integration, $C_{2,18}$ (Ip et al., 2003)
		Track record with past suppliers, $C_{2,\ 19}$ (Cavugil et al., 1995)
		Compatible organization cultures, $C_{2,20}$ (Hajidimitriou and Georgiou, 2002)
		Foreign experience, $C_{2,21}$ (Luo, 1998)
		Willingness to reveal financial records, $C_{2,22}$ (Choi and Hartley, 1996)
	Financial capability, C_3	Net operating margin, $C_{3,1}$ (Mikhailov, 2002)
		Asset/Liability ratio, $C_{3,2}$ (Luo, 1998)
		Gross profit margin, $C_{3,3}$ (Gencer and Gurpinar, 2007)
		The growth rate of business income, $C_{3,4}$ (Mikhailov, 2002)
		Stockholders' equity ratio, $C_{3,5}$
		Cash flow per share, $C_{3,6}$
		Earnings per share of stock, $C_{3,7}$
		Debt/equity ratio, $C_{3,8}$ (Harvey and Lusch, 1995)
		Inventory turnover, $C_{3,9}$
		Liquidity ratio, $C_{3,10}$
		Total revenue, $C_{3,11}$ (Chung et al., 2005)
		Assets rates of increment, $C_{3,12}$ (Dacin et al., 1997)
		Net profits growth rates, $C_{3,13}$ (Lin and Chen, 2004)
		Accounts receivable turnover, $C_{3,14}$
	Technology and knowledge management, C_4	Technical capability, $C_{4,1}$ (Sarkar and Mohapatra, 2006)
		Cost of alternatives, $C_{4,2}$ (Narasimhan et al., 2006)
		Technical advice , $C_{4,3}$ (Dulmin and Mininno, 2003)
		Knowledge of local business practices, $C_{4,4}$ (Hajidimitriou and Georgiou, 2002)

		Information systems and communication, $C_{4,5}$ (Yigin et al., 2007)
		Partners' ability to acquire your firm's special skills, $C_{4,6}$ (Xia and Wu, 2007)
		Obtain partners' local knowledge, $C_{4,7}$ (Dulmin and Mininno, 2003)
		Parent security, $C_{4,8}$ (Cavusgil et al., 1995)
		Willingness to share expertise, $C_{4,9}$ (Ngai et al., 2004)
		Technology innovation, $C_{4,10}$ (Choy et al., 2003)
		Special skills that you can learn from partners, $C_{4,11}$ (Dulmin and Mininno, 2003)
		Product familiarity, $C_{4,12}$ (Dulmin and Mininno, 2003)
		Equipment status of the partners, $C_{4,13}$ (Gencer and Gurpinar, 2007)
		Repair turnaround time, $C_{4,14}$ (Xia and Wu, 2007)
	Marketing capability, C_5	Product/service brand value, $C_{5,1}$ (Luo, 1998)
		Brand loyalty, $C_{5,2}$ (Harvey and Lusch, 1995)
		Sales force, $C_{5,3}$ (Cavusgil et al., 1995)
		Local political and cultural environment, $C_{5,4}$ (Lorange et al., 1992)
		Customer demanded changes, $C_{5,5}$
		Rapid market entry, $C_{5,6}$ (Hajidimitriou and Georgiou, 2002)
		General reputation, $C_{5,7}$ (Choy et al., 2002)
		Better export opportunities, $C_{5,8}$ (Hajidimitriou and Georgiou, 2002)
		Experience with target customers, $C_{5,9}$ (Cavusgil et al., 1995)
		Market position, $C_{5,10}$ (Luo, 1998)
		Market share, $C_{5,11}$ (Cavugil et al., 1995)
		Variation in price, $C_{5,12}$ (Lin and Chen, 2004)
		Price level, $C_{5,13}$ (Mikhailov, 2002)
		Culture of customer service, $C_{5,14}$ (Choy et al., 2002)
		Marketing competence, $C_{5,16}$ (Luo, 1998)
		Supplier representatives' competence, $C_{5,17}$ (Choi and Hartley, 1996)
		Variation in demand quantity, $C_{5,18}$ (Talluri, 1999)
		Customer loyalty, $C_{5,19}$ (Luo, 1998)
		Marketing expertise/knowledge, $C_{5,20}$ (Harvey and Lusch, 1995)
	Industrial and organizational competiveness, C_6	Strategic position in the marketplace, $C_{6,1}$ (Harvey and Lusch, 1995)
		Bargaining power of suppliers, $C_{6,2}$ (Harvey and Lusch, 1995)
		Industry attractiveness, $C_{6,3}$ (Dacin et al., 1997)
		Strategic orientation, $C_{6,4}$ (Luo, 1998)
		Influence on industry, $C_{6,5}$ (Harvey and Lusch, 1995)

		Rivalry among existing firms, $C_{6,6}$ (Harvey and Lusch, 1995)
		Complementarily of product lines, $C_{6,7}$ (Cavugil et al., 1995)
		Corporate market position, $C_{6,8}$ (Harvey and Lusch, 1995)
		Functional competencies, $C_{6,9}$ (Sarkar and Mahapatra, 2006)
		Bargaining power of buyers, $C_{6,10}$ (Harvey and Lusch, 1995)
		Relative power of organization, $C_{6,11}$ (Harvey and Lusch, 1995)
		Unique competencies, $C_{6,12}$ (Dacin et al., 1997)
		Threat of substitute products, $C_{6,13}$ (Harvey and Lusch, 1995)
	Human resource management, C_7	Entrepreneurial creativity, $C_{7,1}$ (Harvey and Lusch, 1995)
		Quality of local personnel, $C_{7,2}$ (Sarkar and Mahapatra, 2006)
		Human resource management skill, $C_{7,3}$ (Yigin et al., 2007)
		Learning ability, $C_{7,4}$ (Luo, 1998)
		Organizational leadership, $C_{7,5}$ (Luo, 1998)
		Product and market expertise, $C_{7,6}$ (Cavusgil et al., 1995)
		Corporate culture, $C_{7,7}$ (Talluri et al., 1999)
		Quality of management team, $C_{7,8}$ (Cavusgil et al., 1995)

Table 5.2: Definitions of linguistic variables for criteria ratings and priority weights (A-9 member linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	(0, 0, 0.0625, 0.125)
Very Poor (VP)	Very Low (VL)	(0.0625, 0.125, 0.1875, 0.25)
Poor (P)	Low (L)	(0.1875, 0.25, 0.3125, 0.375)
Medium Poor (MP)	Medium Low (ML)	(0.3125, 0.375, 0.4375, 0.5)
Medium (M)	Medium (M)	(0.4375, 0.5, 0.5, 0.5625)
Medium Good (MG)	Medium High (MH)	(0.5, 0.5625, 0.625, 0.6875)
Good (G)	High (H)	(0.625, 0.6875, 0.75, 0.8125)
Very Good (VG)	Very High (VH)	(0.75, 0.8125, 0.875, 0.9375)
Absolutely Good (AG)	Absolutely High (AH)	(0.875, 0.9375, 1, 1)

Table 5.8: 3rd level sub-criteria ranking based on utility score

Sub-criteria	U_T Scores (when $\alpha = 0$)	Ranking order	U_T Scores (when $\alpha = 0.5$)	Ranking order	U_T Scores (when $\alpha = 1$)	Ranking order
$C_{1,1}$	0.7298	3	0.8182	3	0.9066	3
$C_{1,2}$	0.8359	1	0.9095	1	0.9831	1
$C_{1,3}$	0.4823	9	0.5707	9	0.6591	9
$C_{1,4}$	0.6591	4	0.7475	4	0.8359	4
$C_{1,5}$	0.6238	5	0.7122	5	0.8006	5
$C_{1,6}$	0.4470	10	0.5354	10	0.6238	10
$C_{1,7}$	0.6238	5	0.7122	5	0.8006	5
$C_{1,8}$	0.3232	12	0.3851	12	0.4470	12
$C_{1,9}$	0.5884	6	0.6768	6	0.7652	6
$C_{1,10}$	0.4823	9	0.5707	9	0.6591	9
$C_{1,11}$	0.5530	7	0.6414	7	0.7298	7
$C_{1,12}$	0.3409	11	0.4116	11	0.4823	11
$C_{1,13}$	0.8006	2	0.8790	2	0.9574	2
$C_{1,14}$	0.5177	8	0.6061	8	0.6945	8
$C_{1,15}$	0.8006	2	0.8790	2	0.9574	2
$C_{1,16}$	0.5177	8	0.6061	8	0.6945	8
$C_{1,17}$	0.5530	7	0.6414	7	0.7298	7
$C_{1,18}$	0.6591	4	0.7475	4	0.8359	4
$C_{1,19}$	0.8006	2	0.8790	2	0.9574	2
$C_{1,20}$	0.5177	8	0.6061	8	0.6945	8
$C_{1,21}$	0.3055	13	0.3674	13	0.4293	13
$C_{1,22}$	0.6591	4	0.7475	4	0.8359	4
$C_{1,23}$	0.3232	12	0.3851	12	0.4470	12
$C_{1,24}$	0.5884	6	0.6768	6	0.7652	6
$C_{1,25}$	0.7298	3	0.8182	3	0.9066	3
$C_{1,26}$	0.8359	1	0.9095	1	0.9831	1
$C_{2,1}$	0.6591	4	0.7475	4	0.8359	4
$C_{2,2}$	0.8006	2	0.8790	2	0.9574	2
$C_{2,3}$	0.5177	8	0.6061	8	0.6945	8
$C_{2,4}$	0.6238	5	0.7122	5	0.8006	5
$C_{2,5}$	0.3409	11	0.4116	11	0.4823	11
$C_{2,6}$	0.8006	2	0.8790	2	0.9574	2

Table 5.8 (Continued)						
Sub-criteria	U_T Scores (when $\alpha = 0$)	Ranking order	U_T Scores (when $\alpha = 0.5$)	Ranking order	U_T Scores (when $\alpha = 1$)	Ranking order
$C_{2,7}$	0.5177	8	0.6061	8	0.6945	8
$C_{2,8}$	0.8006	2	0.8790	2	0.9574	2
$C_{2,9}$	0.5177	8	0.6061	8	0.6945	8
$C_{2,10}$	0.3409	11	0.4116	11	0.4823	11
$C_{2,11}$	0.6238	5	0.7122	5	0.8006	5
$C_{2,12}$	0.8359	1	0.9095	1	0.9831	1
$C_{2,13}$	0.3409	11	0.4116	11	0.4823	11
$C_{2,14}$	0.8006	2	0.8790	2	0.9574	2
$C_{2,15}$	0.5177	8	0.6061	8	0.6945	8
$C_{2,16}$	0.8006	2	0.8790	2	0.9574	2
$C_{2,17}$	0.0403	14	0.1287	14	0.2171	14
$C_{2,18}$	0.3409	11	0.4116	11	0.4823	11
$C_{2,19}$	0.5530	7	0.6414	7	0.7298	7
$C_{2,20}$	0.6238	5	0.7122	5	0.8006	5
$C_{2,21}$	0.4823	9	0.5707	9	0.6591	9
$C_{2,22}$	0.6591	4	0.7475	4	0.8359	4
$C_{3,1}$	0.7298	3	0.8182	3	0.9066	3
$C_{3,2}$	0.8359	1	0.9095	1	0.9831	1
$C_{3,3}$	0.4823	9	0.5707	9	0.6591	9
$C_{3,4}$	0.6591	4	0.7475	4	0.8359	4
$C_{3,5}$	0.6238	5	0.7122	5	0.8006	5
$C_{3,6}$	0.4470	10	0.5354	10	0.6238	10
$C_{3,7}$	0.6238	5	0.7122	5	0.8006	5
$C_{3,8}$	0.3232	12	0.3851	12	0.4470	12
$C_{3,9}$	0.5884	6	0.6768	6	0.7652	6
$C_{3,10}$	0.4823	9	0.5707	9	0.6591	9
$C_{3,11}$	0.5530	7	0.6414	7	0.7298	7
$C_{3,12}$	0.3409	11	0.4116	11	0.4823	11
$C_{3,13}$	0.8006	2	0.8790	2	0.9574	2
$C_{3,14}$	0.5177	8	0.6061	8	0.6945	8
$C_{4,1}$	0.8006	2	0.8790	2	0.9574	2
$C_{4,2}$	0.5177	8	0.6061	8	0.6945	8

Table 5.8 (Continued)						
Sub-criteria	U_T Scores (when $\alpha = 0$)	Ranking order	U_T Scores (when $\alpha = 0.5$)	Ranking order	U_T Scores (when $\alpha = 1$)	Ranking order
$C_{4,3}$	0.5530	7	0.6414	7	0.7298	7
$C_{4,4}$	0.6591	4	0.7475	4	0.8359	4
$C_{4,5}$	0.8006	2	0.8790	2	0.9574	2
$C_{4,6}$	0.5177	8	0.6061	8	0.6945	8
$C_{4,7}$	0.8006	2	0.8790	2	0.9574	2
$C_{4,8}$	0.6591	4	0.7475	4	0.8359	4
$C_{4,9}$	0.3232	12	0.3851	12	0.4470	12
$C_{4,10}$	0.5884	6	0.6768	6	0.7652	6
$C_{4,11}$	0.4823	9	0.5707	9	0.6591	9
$C_{4,12}$	0.5530	7	0.6414	7	0.7298	7
$C_{4,13}$	0.3409	11	0.4116	11	0.4823	11
$C_{4,14}$	0.8006	2	0.8790	2	0.9574	2
$C_{5,1}$	0.7298	3	0.8182	3	0.9066	3
$C_{5,2}$	0.8359	1	0.9095	1	0.9831	1
$C_{5,3}$	0.4823	9	0.5707	9	0.6591	9
$C_{5,4}$	0.6591	4	0.7475	4	0.8359	4
$C_{5,5}$	0.6238	5	0.7122	5	0.8006	5
$C_{5,6}$	0.0403	14	0.1287	14	0.2171	14
$C_{5,7}$	0.3409	11	0.4116	11	0.4823	11
$C_{5,8}$	0.5530	7	0.6414	7	0.7298	7
$C_{5,9}$	0.6238	5	0.7122	5	0.8006	5
$C_{5,10}$	0.4823	9	0.5707	9	0.6591	9
$C_{5,11}$	0.6591	4	0.7475	4	0.8359	4
$C_{5,12}$	0.3409	11	0.4116	11	0.4823	11
$C_{5,13}$	0.6238	5	0.7122	5	0.8006	5
$C_{5,14}$	0.8359	1	0.9095	1	0.9831	1
$C_{5,15}$	0.3409	11	0.4116	11	0.4823	11
$C_{5,16}$	0.8006	2	0.8790	2	0.9574	2
$C_{5,17}$	0.5177	8	0.6061	8	0.6945	8
$C_{5,18}$	0.8006	2	0.8790	2	0.9574	2
$C_{5,19}$	0.6238	5	0.7122	5	0.8006	5
$C_{6,1}$	0.4823	9	0.5707	9	0.6591	9

Table 5.8 (Continued)

Sub-criteria	U_T Scores (when $\alpha = 0$)	Ranking order	U_T Scores (when $\alpha = 0.5$)	Ranking order	U_T Scores (when $\alpha = 1$)	Ranking order
$C_{6,2}$	0.3409	11	0.4116	11	0.4823	11
$C_{6,3}$	0.6238	5	0.7122	5	0.8006	5
$C_{6,4}$	0.4823	9	0.5707	9	0.6591	9
$C_{6,5}$	0.6591	4	0.7475	4	0.8359	4
$C_{6,6}$	0.6591	4	0.7475	4	0.8359	4
$C_{6,7}$	0.6238	5	0.7122	5	0.8006	5
$C_{6,8}$	0.8006	2	0.8790	2	0.9574	2
$C_{6,9}$	0.6591	4	0.7475	4	0.8359	4
$C_{6,10}$	0.3232	12	0.3851	12	0.4470	12
$C_{6,11}$	0.5884	6	0.6768	6	0.7652	6
$C_{6,12}$	0.4823	9	0.5707	9	0.6591	9
$C_{6,13}$	0.5530	7	0.6414	7	0.7298	7
$C_{7,1}$	0.3409	11	0.4116	11	0.4823	11
$C_{7,2}$	0.5530	7	0.6414	7	0.7298	7
$C_{7,3}$	0.4823	9	0.5707	9	0.6591	9
$C_{7,4}$	0.6591	4	0.7475	4	0.8359	4
$C_{7,5}$	0.6591	4	0.7475	4	0.8359	4
$C_{7,6}$	0.3232	12	0.3851	12	0.4470	12
$C_{7,7}$	0.5884	6	0.6768	6	0.7652	6
$C_{7,8}$	0.4823	9	0.5707	9	0.6591	9

Table 5.9: 3rd level sub-criteria ranking based on fuzzy similarity measure *(Degree of Similarity Concept)*

Sub-Criteria	**S (A, B) by (Chen, 1996)**	**Ranking order**	**S (A, B) by (Hsieh and Chen, 1999)**	**Ranking order**	**S(A, B) by (Chen and Chen, 2003b)**	**Ranking order**	**S(A, B) by (Yong et al., 2004)**	**Ranking order**	**S(A, B) (Chen, 2006)**	**Ranking order**	**S(A, B) (Sridevi and Nadarajan, 2009)**	**Ranking order**
$C_{1,1}$	0.8021	1	0.931504	5	0.755039	4	0.761764	3	0.791361	4	0.56875	4
$C_{1,2}$	0.756825	3	0.87544	10	0.653034	10	0.665981	8	0.733737	10	0.443208	10
$C_{1,3}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{1,4}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{1,5}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{1,6}$	0.8021	1	0.887731	9	0.676091	9	0.640501	10	0.78637	8	0.509281	8
$C_{1,7}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{1,8}$	0.7429	5	0.811216	12	0.508811	12	0.478761	12	0.669319	12	0.332723	12
$C_{1,9}$	0.8021	1	0.974215	3	0.755598	3	0.739347	4	0.791644	3	0.569172	3
$C_{1,10}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{1,11}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{1,12}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{1,13}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{1,14}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{1,15}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{1,16}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{1,17}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{1,18}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{1,19}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{1,20}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{1,21}$	0.73665	6	0.803073	13	0.496055	13	0.463788	13	0.662693	13	0.318717	13
$C_{1,22}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{1,23}$	0.7429	5	0.811216	12	0.508811	12	0.478761	12	0.669319	12	0.332723	12
$C_{1,24}$	0.8021	1	0.974215	3	0.755598	3	0.739347	4	0.791644	3	0.569172	3
$C_{1,25}$	0.8021	1	0.931504	5	0.755039	4	0.761764	3	0.791361	4	0.56875	4

Table 5.9 (Continued)

Sub-Criteria	S (A, B) by (Chen, 1996)	Ranking order	S (A, B) by (Hsieh and Chen, 1999)	Ranking order	S(A, B) by (Chen and Chen, 2003b)	Ranking order	S(A, B) by (Yong et al., 2004)	Ranking order	S(A, B) (Chen, 2006)	Ranking order	S(A, B) (Sridevi and Nadarajan, 2009)	Ranking order
$C_{1,26}$	0.756825	3	0.87544	10	0.653034	10	0.665981	8	0.733737	10	0.443208	10
$C_{2,1}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{2,2}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{2,3}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{2,4}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{2,5}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{2,6}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{2,7}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{2,8}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{2,9}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{2,10}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{2,11}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{2,12}$	0.756825	3	0.87544	10	0.653034	10	0.665981	8	0.733737	10	0.443208	10
$C_{2,13}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{2,14}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{2,15}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{2,16}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{2,17}$	0.57195	7	0.70723	14	0.319103	14	0.253928	14	0.550466	14	0.080285	14
$C_{2,18}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{2,19}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{2,20}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{2,21}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{2,22}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{3,1}$	0.8021	1	0.931504	5	0.755039	4	0.761764	3	0.791361	4	0.56875	4
$C_{3,2}$	0.756825	3	0.87544	10	0.653034	10	0.665981	8	0.733737	10	0.443208	10
$C_{3,3}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7

Table 5.9 (Continued)

Sub-Criteria	S (A, B) by (Chen, 1996)	Ranking order	S (A, B) by (Hsieh and Chen, 1999)	Ranking order	S(A, B) by (Chen and Chen, 2003b)	Ranking order	S(A, B) by (Yong et al., 2004)	Ranking order	S(A, B) (Chen, 2006)	Ranking order	S(A, B) (Sridevi and Nadarajan, 2009)	Ranking order
$C_{3,4}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{3,5}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{3,6}$	0.8021	1	0.887731	9	0.676091	9	0.640501	10	0.78637	8	0.509281	8
$C_{3,7}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{3,8}$	0.7429	5	0.811216	12	0.508811	12	0.478761	12	0.669319	12	0.332723	12
$C_{3,9}$	0.8021	1	0.974215	3	0.755598	3	0.739347	4	0.791644	3	0.569172	3
$C_{3,10}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{3,11}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{3,12}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{3,13}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{3,14}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{4,1}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{4,2}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{4,3}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{4,4}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{4,5}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{4,6}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{4,7}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{4,8}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{4,9}$	0.7429	5	0.811216	12	0.508811	12	0.478761	12	0.669319	12	0.332723	12
$C_{4,10}$	0.8021	1	0.974215	3	0.755598	3	0.739347	4	0.791644	3	0.569172	3
$C_{4,11}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{4,12}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{4,13}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{4,14}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{5,1}$	0.8021	1	0.931504	5	0.755039	4	0.761764	3	0.791361	4	0.56875	4

Table 5.9 (Continued)

Sub-Criteria	S (A, B) by (Chen, 1996)	Ranking order	S (A, B) by (Hsieh and Chen, 1999)	Ranking order	S(A, B) by (Chen and Chen, 2003b)	Ranking order	S(A, B) by (Yong et al., 2004)	Ranking order	S(A, B) (Chen, 2006)	Ranking order	S(A, B) (Sridevi and Nadarajan, 2009)	Ranking order
$C_{5,2}$	0.756825	3	0.87544	10	0.653034	10	0.665981	8	0.733737	10	0.443208	10
$C_{5,3}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{5,4}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{5,5}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{5,6}$	0.57195	7	0.70723	14	0.319103	14	0.253928	14	0.550466	14	0.080285	14
$C_{5,7}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{5,8}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{5,9}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{5,10}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{5,11}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{5,12}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{5,13}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{5,14}$	0.756825	3	0.87544	10	0.653034	10	0.665981	8	0.733737	10	0.443208	10
$C_{5,15}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{5,16}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{5,17}$	0.8021	1	0.928965	6	0.715845	6	0.689927	7	0.789704	6	0.539226	6
$C_{5,18}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9
$C_{5,19}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{6,1}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{6,2}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{6,3}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{6,4}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{6,5}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{6,6}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{6,7}$	0.8021	1	0.998535	1	0.775475	2	0.764055	2	0.792093	2	0.584144	2
$C_{6,8}$	0.77245	2	0.893363	8	0.691742	8	0.699214	6	0.759053	9	0.487967	9

Table 5.9 (Continued)												
Sub-Criteria	**S (A, B) by (Chen, 1996)**	**Ranking order**	**S (A, B) by (Hsieh and Chen, 1999)**	**Ranking order**	**S(A, B) by (Chen and Chen, 2003b)**	**Ranking order**	**S(A, B) by (Yong et al., 2004)**	**Ranking order**	**S(A, B) (Chen, 2006)**	**Ranking order**	**S(A, B) (Sridevi and Nadarajan, 2009)**	**Ranking order**
$C_{6,9}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{6,10}$	0.7429	5	0.811216	12	0.508811	12	0.478761	12	0.669319	12	0.332723	12
$C_{6,11}$	0.8021	1	0.974215	3	0.755598	3	0.739347	4	0.791644	3	0.569172	3
$C_{6,12}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{6,13}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{7,1}$	0.7554	4	0.823746	11	0.546101	11	0.511317	11	0.70255	11	0.369273	11
$C_{7,2}$	0.8021	1	0.951052	4	0.735722	5	0.714637	5	0.790848	5	0.554199	5
$C_{7,3}$	0.8021	1	0.90788	7	0.695968	7	0.665215	9	0.788212	7	0.524254	7
$C_{7,4}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{7,5}$	0.8021	1	0.977008	2	0.794792	1	0.788763	1	0.792196	1	0.598695	1
$C_{7,6}$	0.7429	5	0.811216	12	0.508811	12	0.478761	12	0.669319	12	0.332723	12
$C_{7,7}$	0.8021	1	0.974215	3	0.755598	3	0.739347	4	0.791644	3	0.569172	3
$C_{7,8}$	0.8021	1	0.90788	7	0.695968	7	0.665215	6	0.788212	7	0.524254	7

5.2 Supplier Selection in ASC using Fuzzy-MULTIMOORA

5.2.1 Overview

Today's more dynamic business environment increases the need for greater agility in supply chains, which increases both the importance and frequency of partner selection decision-making.

An agile supply chain (ASC) needs to be highly flexible and to be able to be reconfigured quickly in response to changes in the unpredictable business environment. Thus, an ASC can be thought of as a dynamic network of member companies, whose constituents and structure are likely to need to change frequently. The successful operation of an ASC largely depends upon the firm's ability to select the most appropriate potential partners in any given situation (Wu and Barnes, 2010). The supplier/partner selection process is particularly complex when viewed from a supply chain perspective as it involves a series of inter-related decisions about suppliers, which impact both the formation and the performance of the supply chain as a whole (Wu and Barnes, 2012).

The contribution of this work is the development of a framework and a decision model for supplier/partner selection in agile supply chain by utilizing a fuzzy logic integrated with MULTIMOORA method (Brauers et al., 2011). The study presents a host of metrics and measures from extant literature on agility, which has been utilized in the development of the appraisement framework and model. Empirical data has been analyzed to exhibit application feasibility of the proposed approach.

5.2.2 Problem Statement

Supply chain management can be considered as one of the most important aspects of production planning and control (Yigin et al. 2007). It provides the link from suppliers to customers in the planning, manufacturing and controlling of raw materials and products (Markland et al. 1995).

Recently, in order to respond efficiently and effectively to increasingly dynamic and volatile markets, many businesses have adopted the concept of agile supply chains or networks (Christopher 2000). An agile supply chain (ASC) can be considered as a dynamic network of member companies, the formation of which is likely to need to change frequently in response to fast-changing markets. In ASCs, the task of partner selection is thus not a one-off infrequent activity. A key requirement of operating an ASC is the ability to adopt the most appropriate structure and assign the most suitable order quantities to the most appropriate supply partners in any given circumstance (Wu et al., 2009). However, frequently changing customer demands create increased uncertainty and ambiguity for this decision making process. Thus, the importance of supplier selection process has increased along with its complexity (Sarkar and Mohapatra 2006). Therefore, an effective supply partner selection process is essential for the successful operation of an ASC. Efficient ASCs are considered to be the solution to meet the frequently changing customer demand for high quality, short lead times, low cost, and high customer service levels. It is generally accepted that the successful performance of an ASC depends heavily on the construction of the supply network and the choice of the right partners (Wu et al., 2009).

In this context, present work highlights exploration of Interval-Valued Fuzzy Numbers (IVFNs) set theory and MULTIROORA method towards effective appraisement and selection of potential candidate suppliers in ASC. Subjective appraisement indices have been evaluated in terms of performance extent as well as priority importance given by the decision-makers (DMs) linguistic information. In order to overcome uncertainty, ambiguity and vagueness arising from linguistic evaluation information, fuzzy logic has been adapted at this stage, to transform linguistic information into appropriate fuzzy numbers. Using MULTIMOORA method, multiple evaluation indices have then been aggregated to compute an overall evaluation index to facilitate suppliers' ranking and finally selecting the best alternative supplier.

5.2.3 The Crisp MULTIMOORA Method

The Multi-Objective Optimization by Ratio Analysis (MOORA) method was introduced by Brauers and Zavadakas (2006). Brauers and Zavadakas (2010) extended the method to make it more robust as MULTIMOORA (MOORA plus the full multiplicative form).

MOORA method begins with matrix X where its elements x_{ij} denote i_{th} alternative of j_{th} objective $(i = 1,2,...,m;\ j = 1,2,...,n)$. MOORA method consists of two parts: the Ratio System and the Reference Point Approach. The MULTIMOORA method includes internal normalization and treats originally all the objectives equally important. In principle all stakeholders interested in the issue only could give more importance to an objective. Therefore, they could either multiply the dimensionless number representing the response on an objective with a significance coefficient or they could decide beforehand to split an objective into different sub-objectives.

The Ratio System of MOORA

Ratio System defines data normalization by comparing alternative of an objective to all values of the objective:

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{5.3}$$

Here x_{ij}^* denotes i_{th} alternative of j_{th} objective. Usually these numbers belong to the interval [0, 1]. These indicators are added (if desirable value of indicator is maximum) or subtracted (if desirable value is minimum), thus the summarizing index of each alternative is derived in this way:

$$y_i^* = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^*, \tag{5.4}$$

Here $g = 1,...,n$ denotes number of objectives to be maximized. Then every ratio is given the rank: the higher the index, the higher the rank.

In some cases, it is often observed that some attributes are more important than the others. In order to give more importance to an attribute, it could be multiplied with its corresponding weight (significance coefficient) (Brauers and Zavadskas, 2009; Chakraborty, 2011). When these attribute weights are taken into consideration, Eq. 5.4 becomes as follows:

$$y_i^* = \sum_{j=1}^{g} w_j x_{ij}^* - \sum_{j=g+1}^{n} w_j x_{ij}^*, \quad j = 1,2,...,n. \tag{5.5}$$

Here w_j is the weight of j_{th} attribute.

The Reference Point of MOORA

Reference point approach is based on the Ratio System. The Maximal Objective Reference Point (vector) is found according to ratios found by employing Eq. 5.6 The j_{th} coordinate of the reference point can be described as ($r_j = \max x_{ij}^*$) in case of maximization. Every coordinate of this vector represents maximum or minimum of certain objective (indicator). Then every element of normalized response matrix is recalculated and final rank is given according to deviation from the reference point and the Min-Max Metric of Tchebycheff:

$$\min_i \left(\max_j \left| r_j - x_{ij}^* \right| \right) \tag{5.6}$$

The Full Multiplicative Form and MULTIMOORA

(Brauers and Zavadskas, 2006) proposed MOORA to be updated by the Full Multiplicative Form method embodying maximization as well as minimization of purely multiplicative utility function. Overall utility of the i_{th} alternative can be expressed as dimensionless number:

$$U_i^{'} = \frac{A_i}{B_i} \tag{5.7}$$

Here $A_i = \prod_{j=1}^{g} x_{ij}; i = 1,2,...,m$ denotes the product of objectives of the i_{th} alternative to be maximized with $g = 1,2,...,n$ being the number of objectives to be maximized and where $B_i = \prod_{j=g+1}^{n} x_{ij}; i = 1,2,...,m$ denotes the product of objectives of the i_{th} alternative to be minimized with $n-g$ being the number of objectives (indicators) to be minimized. Thus MULTIMOORA summarizes MOORA (i.e. Ratio System and Reference Point) and the Full Multiplicative Form.

5.2.4 MULTIMOORA Method Based upon IV Trapezoidal Fuzzy Numbers

Let $k = 1,2,..., K$ denotes the k_{th} expert involved in a decision-making process. Suppose that the experts provide ratings for each i_{th} alternative against each j_{th} criterion with $i = 1,2,...,m$ and $j = 1,2,...,n$. The set of criteria can be split into two subsets, namely those of cost criteria, C, and benefit criteria, B. Cost criteria are to be minimized whereas; benefit criteria are to be maximized. Each criterion can be attributed with respective weight ϖ_j, such that $\varpi_j \geq 0$, and $\sum_j \varpi_j = 1$.

Step 1: Each of decision-makers constructs his own decision matrix:

$\left(\tilde{\tilde{A}}^k\right)_{m \times n}$ with elements $\tilde{\tilde{a}}_{ij}^k = \left[\left(a_{ijk1}^L, a_{ijk2}^L, a_{ijk3}^L, a_{ijk4}^L; w_{ijk}^L\right), \left(a_{ijk1}^U, a_{ijk2}^U, a_{ijk3}^U, a_{ijk4}^U; w_{ijk}^U\right)\right]$ being responses of alternatives on criteria.

Step 2: Individual decision matrices are aggregated by employing the GITFNOWGA operator.

$$GITFNOWGA_w\left(\tilde{\tilde{a}}_{ij}^1, \tilde{\tilde{a}}_{ij}^2, ..., \tilde{\tilde{a}}_{ij}^K\right) = \prod_{k=1}^{K}\left(a_{ij}^{\sigma(k)}\right)^{w_k}, \forall i, j, \tag{5.8}$$

Here w_k is the weight of the k_{th} largest response obtained (Baležentis and Zeng, 2013).

Also,

$$\tilde{\tilde{a}}_{ij} = \left[\left(a_{ij1}^L, a_{ij2}^L, a_{ij3}^L, a_{ij4}^L; w_{ij}^L\right), \left(a_{ij1}^U, a_{ij2}^U, a_{ij3}^U, a_{ij4}^U; w_{ij}^U\right)\right]$$

Step 3: In case some of criteria involve numeric data, the normalization has to be carried out.

$$\tilde{\tilde{x}}_{ij} = \left[\left(\frac{a_{ij1}^L}{d_j}, \frac{a_{ij2}^L}{d_j}, \frac{a_{ij3}^L}{d_j}, \frac{a_{ij4}^L}{d_j}; w_{ij}^L\right), \left(\frac{a_{ij1}^U}{d_j}, \frac{a_{ij2}^U}{d_j}, \frac{a_{ij3}^U}{d_j}, \frac{a_{ij4}^U}{d_j}; w_{ij}^U\right)\right] \tag{5.9}$$

$$= \left[\left(x_{ij1}^L, x_{ij2}^L, x_{ij3}^L, x_{ij4}^L; w_{ij}^L\right), \left(x_{ij1}^U, x_{ij2}^U, x_{ij3}^U, x_{ij4}^U; w_{ij}^U\right)\right],$$

$$j = 1,2,\ldots,n; i = 1,2,\ldots,n.$$

Here $d_j = \sqrt{\sum_{i=1}^{m}\sum_{p=1}^{4}\left(a_{ijp}^L\right)^2 + \sum_{i=1}^{m}\sum_{p=1}^{4}\left(a_{ijp}^U\right)^2}$,

$p = \{1,2,3,4\}$ for $\forall j = 1,2,\ldots,n.$

Step 4: The Ratio System

The normalized values are added up for the benefit criteria and subtracted for the cost criteria:

$$RS_i = \sum_{j\in B}\tilde{\tilde{x}}_{ij} - \sum_{j\in C}\tilde{\tilde{x}}_{ij}$$

$$= \left[\left(RS_{i1}^L, RS_{i2}^L, RS_{i3}^L, RS_{i4}^L; w_{RS_i}^L\right), \left(RS_{i1}^U, RS_{i2}^U, RS_{i3}^U, RS_{i4}^U; w_{RS_i}^U\right)\right] \tag{5.10}$$

Here RS_i denotes the overall utility of the i_{th} alternative in terms of the Ratio System. The alternatives are then ranked by measuring their distances from the origin point. Specially, alternatives with higher distances receive higher ranks.

Step 5: The Reference Point Approach

For the sake of convenience one can employ the Maximal Utopian Reference Point (MURP), rather than the Maximal Objective Reference Point. In case of the generalized interval-valued trapezoidal fuzzy numbers, MURP is defined as follows:

$$\tilde{\tilde{r}}_j = \begin{cases} (1,1,1,1;1), & \forall j \in B \\ (0,0,0,0;1), & \forall j \in C \end{cases} \tag{5.11}$$

Thereafter, maximal deviation from the MURP for each alternative is to be identified:

$$\max_j d\left(\tilde{\tilde{r}}_j, \tilde{\tilde{x}}_{ij}\right) \quad (5.12)$$

Then, the alternatives can be ranked by minimizing the maximal deviances found in Eq. 5.11.

Step 6: The Full Multiplicative Form

The fuzzy utility of the i_{th} alternative is obtained.

$$\tilde{\tilde{U}}_i = \frac{\tilde{\tilde{A}}_i}{\tilde{\tilde{B}}_i} \quad (5.13)$$

Here $\tilde{\tilde{A}}_i = \prod_{j \in B} \tilde{\tilde{x}}_{ij}, i = 1,2,...,m$ denotes the product of objectives of the i_{th} alternative to be maximized with B being the set of objectives to be maximized, and where $\tilde{\tilde{B}}_i = \prod_{j \in C} \tilde{\tilde{x}}_{ij}$ denotes the product of objectives of the i_{th} alternative to be minimized with C being the set of objectives (indicators) need to be minimized. The alternatives are to be ranked in descending order of $\tilde{\tilde{U}}_i$.

Step 7: The Dominance theory (Brauers and Zavadskas, 2011) is employed to aggregate the three ranks provided by respective parts of MULTIMOORA.

As one can note, the MULTIMOORA involves multiplication and division operations. The use of the most extreme linguistic values of zero therefore should be avoided. Otherwise, alternatives attributed with particularly low values against some criteria should be dropped from the further analysis.

5.2.5 Empirical Research

The performance evaluation index platform towards selection of appropriate supplier/partner in agile supply chain adapted in this work has already been shown in (Table 5.1 in Section 5.1). The two-level hierarchical model consists of various indices: measures and metrics. Production and Logistics Management (C_1), Partnership Management (C_2), Financial Capability (C_3), Technology and Knowledge Management (C_4), Marketing Capability (C_5), Industrial and Organizational Competitiveness (C_6), and Human Resource Management (C_7) etc. have been considered as the 1st level indices (called measures) followed by 2nd level sub-indices which encompass numerous performance metrics. A MULTIMOORA method combined with Interval-Valued Fuzzy Numbers Set (IVFNS) has been explored in perceptive to evaluate a suppliers'/partners' performance alternative in agile supply chain. This method has been found fruitful in solving such a group multi-criteria decision making problem under uncertain environment due to inherent vagueness, inconsistency and incompleteness associated with decision-makers' subjective evaluation information.

An empirical study has been carried out for the evaluation of supplier/partner's performance in agile supply chain in fuzzy environment. Assume that a committee of five decision makers such as: $DM_1, DM_2, DM_3, DM_4, DM_5$ has been constructed from academicians, manager of production unit, marketing unit, material purchasing unit and his team. Also assume that there were three alternatives suppliers/partners such as: A_1, A_2, and A_3.

In this study, the priority weights against performance measures-metrics and corresponding appropriateness ratings have been expressed in linguistic variables which have been further transformed into IV-trapezoidal fuzzy numbers. These linguistic variables corresponding to weight assignment of various performance measures-metrics (both in 1st and 2nd level) has been expressed in fuzzy numbers by 1-9 scale as shown in Table 5.10. Similarly, the linguistic performance ratings of individual 2nd level evaluation metrics have also been expressed in fuzzy numbers by 1-9 scale shown in (Table 5.10). The procedural steps and its implementation outcome have been summarized as follows:

Step 1: Decision-Makers' judgment on performance ratings and importance weights of various performance measures/metrics using linguistic terms

For evaluating importance weights of numerous measures/metrics (both 1st as well as 2nd level of the evaluation hierarchy), as well as appropriateness rating of 2nd level sub-indices (metrics); a committee of fives decision-makers (DMs), $DM_1, DM_2, DM_3, DM_4, DM_5$ has been formed to express their subjective preferences (priority importance) in linguistic terms shown in (Table 5.10) which have been further transformed into IV-fuzzy number.

The linguistic variables for assessing importance weights of various evaluation indices have been given by the decision-makers (DMs) shown in (Appendix: Tables 5.11-5.12). Similarly the linguistic judgment reflecting appropriateness rating/performance of various 2nd level sub-indices have been shown in (Appendix: Tables 5.13-5.15); for alternative supplier/partner 1, 2, and 3 respectively.

Step 2: Approximation of the linguistic terms by IV trapezoidal fuzzy numbers

Using the concept of generalized trapezoidal Interval-Valued Fuzzy Numbers in fuzzy set theory, the linguistic variables have been approximated by fuzzy numbers shown in (Table 5.10). Next, based on simple aggregation (average) rule, the fuzzy appropriateness weights for (1^{st} and 2^{nd} level evaluation indices) and appropriateness rating for individual 2^{nd} level sub-indices have been computed, shown in (Appendix: Tables 5.16-5.18) in favour of A_1, A_2, and A_3 alternatives respectively. For the sake of computation simplicity, instead of using GITFNOWGA operator, the simple average rule has been adapted here to accumulate multiple decision-makers' opinion against a particular evaluation characteristic of a particular performance metric. Similarly, the fuzzy appropriateness ratings of 2^{nd} level sub-indices have been assessed and shown in (Appendix: Tables 5.16-5.18).

Step 3: Estimation of appraisement index i.e. fuzzy performance rating of 1^{st} level indices

FPI represents the Fuzzy Performance Index. The concept of fuzzy performance index employed to compute the appropriateness rating of various 1^{st} level indices, shown in (Tables 5.19-5.21), in favour of alternatives A_1, A_2, and A_3, respectively.

Appropriateness rating (also called FPI) for each of the 1^{st} level evaluation index U_i (rating of i_{th} index) has been computed as follows:

$$FPI = U_i = \frac{\sum U_{ij} \otimes w_{ij}}{\sum w_{ij}} \tag{5.14}$$

In this expression (Eq. 5.14) U_{ij} is denoted as the aggregated fuzzy appropriateness rating against j_{th} sub-index (at 2^{nd} level) which is under i_{th} main index in the 1^{st} level. w_{ij} is the aggregated fuzzy weight against j_{th} sub-index (at 2^{nd} level) which is under i_{th} main index at 1^{st} level.

Step 4: Normalization

All of the indices/metric have been assumed benefit in nature and expressed in the generalized interval-valued trapezoidal fuzzy numbers; but usually these numbers belong to the interval [0; 1]; therefore, normalization has to be carried out by employing the equation, (Eq. 5.9) (Table 5.22) to get weighted normalized decision-making matrix.

Step 5: The Ratio System

The Ratio System, the normalized values are added up for the benefit criteria and subtracted for the cost criteria (Eqs. 5.4-5.5) shown in (Table 5.23).

Step 6: Reference Point Approach

We define the Reference Point: $\tilde{\tilde{r}}_i = (1,1,1,1;1)$

Thus, rank the alternatives in terms of their distances. The alternative, with smaller distance measure corresponds to higher ranking position (Table 5.24).

Step 7: Full Multiplicative Form

The Eq. 5.13 has been employed to obtain ranks for each of alternatives according to the Full Multiplicative Form as shown in (Table 5.25).

Step 8: Selection of Best Alternative

By employing the *Ratio System*, the *Reference Point* and the *Full Multiplicative Form* to rank the candidate suppliers/partners in agile supply chain; the *Dominance theory* (Brauers and Zavadskas, 2011) has been employed to summarize aforesaid three different ranking orders provided by respective parts of IVFN based MULTIMOORA method. Table 5.26 presents appropriate ranking order. According to the multi-criteria evaluation, the first alternative (A_1) should be best choice as per the judgment of decision makers, whereas the second alternative (A_2) is the second-best choice. At the other end of spectrum, third alternative A_3 is the worst choice.

5.2.6 Concluding Remarks

Agile Supply Chain Management (ASCM) combines of agile conception and SCM, which makes enterprises work together through collaborative manage and improves enterprise agility; even whole SC. The key of building double profit ASCM is select agile, strength and consistent supplier (Lin, 2004; Yahya and Kingsman, 1999; Charles and John, 1993). Supplier's competition ability analysis is the precondition of supplier selection. It can also promote SCM efficiency. Traditional supply relationship can't adapt global competition and product requirement variety. For realizing low cost, high quality, flexible produce and fast respond, enterprise business reformer must include supplier evaluation and selection (Wu et al., 2008). The aforesaid study considered multiple subjective performance indices for the evaluation as well as selection of appropriate supplier/partner in agile supply chain. Due to fuzziness associated with decision-makers (expert panel) subjective evaluation; this study utilized an approach based on interval-valued fuzzy set theory combined with MULTIMOORA method. The theory of dominance has been applied in the proposed evaluation model which summarized the ranking order provided by exploring different concepts of MULTIMOORA–FG, namely the Fuzzy Ratio System, the fuzzy Reference Point, and the fuzzy Full Multiplicative Form and finally, the result revealed that A_1 is the most suitable alternative in perceptive of overall performance in relation to agile supply chain. The approach is very helpful in dealing with variety of multi-criteria group decision making problems involving subjective evaluation information.

Table 5.10: A 9-member linguistic term set and their corresponding interval-valued fuzzy numbers

Linguistic terms for weight assignment	Linguistic terms for ratings	Interval-Valued trapezoidal fuzzy numbers
Absolutely low, AL	Absolutely poor, AP	[(0.0, 0.0, 0.0, 0.0; 1.0), (0.0, 0.0, 0.0, 0.0; 1.0)]
Very low, VL	Very poor, VP	[(0.0075, 0.0075, 0.015, 0.0525; 0.5), (0.0, 0.0, 0.02, 0.07; 1.0)]
Low, L	Poor, P	[(0.0875, 0.12, 0.16, 0.1825; 0.5), (0.04, 0.10, 0.18, 0.23; 1.0)]
Fairly low, FL	Fairly poor, FP	[(0.2325, 0.255, 0.325, 0.3575; 0.5), (0.17, 0.22, 0.36, 0.42; 1.0)]
Medium, M	Medium, M	[(0.4025, 0.4525, 0.5375, 0.5676; 0.5), (0.32, 0.41, 0.58, 0.65; 1.0)]
Fairly High, FH	Fairly satisfactory, FS	[(0.65, 0.6725, 0.7575, 0.79; 0.5), (0.58, 0.63, 0.80, 0.86; 1.0)]
High, H	Satisfactory, S	[(0.7825, 0.815, 0.885, 0.9075; 0.5), (0.72, 0.78, 0.92, 0.97; 1.0)]
Very High, VH	Very Impressive, VI	[(0.9475, 0.985, 0.9925, 0.9925; 0.5), (0.93, 0.98, 1.0, 1.0; 1.0)]
Absolutely high, AH	Absolutely impressive, AI	[(1.0, 1.0, 1.0, 1.0; 1.0), (1.0, 1.0, 1.0, 1.0; 1.0)]

Table 5.19: Performance ratings and weights of 1^{st} level indices assigned by the decision-makers **(Alternative 1)**

1^{st} Level indices (C_i)	Computed fuzzy appropriateness rating,(U_i)	Aggregated fuzzy priority weight,(W_i)
C_1	[(0.536,0.600,0.750,0.820;0.500),(0.429,0.534,0.837,0.995;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_2	[(0.552,0.619,0.767,0.837;0.500),(0.446,0.553,0.8541.013;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_3	[(0.508,0.573,0.733,0.806;0.500),(0.397,0.503,0.827,0.997;1.000)]	[(0.692,0.855,0.903,0.918;0.500),(0.776,0.830,0.928,0.960;1.000)]
C_4	[(0.520,0.584,0.730,0.800;0.500),(0.416,0.519,0.817,0.975;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_5	[(0.537,0.601,0.758,0.832;0.500),(0.427,0.532,0.850,1.017;1.000)]	[(0.789,0.821,0.881,0.901;0.500),(0.734,0.790,0.912,0.954;1.000)]
C_6	[(0.548,0.612,0.756,0.824;0.500),(0.444,0.548,0.840,0.994;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_7	[(0.523,0.585,0.742,0.816;0.500),(0.413,0.517,0.833,1.001;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]

Table 5.20: Performance ratings and weights of 1st level indices assigned by the decision-makers **(Alternative 2)**

1st Level indices (C_i)	Computed fuzzy appropriateness rating,(U_i)	Aggregated fuzzy priority weight,(W_i)
C_1	[(0.690,0.760,0.917,0.989;0.500),(0.576,0.689,1.008,1.169;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_2	[(0.671,0.742,0.899,0.972;0.500),(0.557,0.672,0.991,1.154;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_3	[(0.674,0.746,0.913,0.988;0.500),(0.556,0.672,1.010,1.183;1.000)]	[(0.692,0.855,0.903,0.918;0.500),(0.776,0.830,0.928,0.960;1.000)]
C_4	[(0.711,0.783,0.945,1.020;0.500),(0.594,0.711,1.040,1.206;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_5	[(0.669,0.741,0.901,0.975;0.500),(0.554,0.670,0.994,1.161;1.000)]	[(0.789,0.821,0.881,0.901;0.500),(0.734,0.790,0.912,0.954;1.000)]
C_6	[(0.710,0.778,0.928,0.998;0.500),(0.599,0.710,1.014,1.169;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_7	[(0.690,0.761,0.919,0.993;0.500),(0.575,0.690,1.012,1.177;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]

Table 5.21: Performance ratings and weights of 1st level indices assigned by the decision-makers **(Alternative 3)**

1st Level indices (C_i)	Computed fuzzy appropriateness rating,(U_i)	Aggregated fuzzy priority weight,(W_i)
C_1	[(0.242,0.287,0.393,0.448;0.500),(0.167,0.242,0.454,0.581;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_2	[(0.251,0.297,0.409,0.468;0.500),(0.172,0.248,0.475,0.610;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_3	[(0.271,0.318,0.435,0.494;0.500),(0.190,0.268,0.505,0.642;1.000)]	[(0.692,0.855,0.903,0.918;0.500),(0.776,0.830,0.928,0.960;1.000)]
C_4	[(0.271,0.319,0.436,0.496;0.500),(0.189,0.269,0.505,0.644;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_5	[(0.250,0.296,0.408,0.466;0.500),(0.172,0.248,0.474,0.607;1.000)]	[(0.789,0.821,0.881,0.901;0.500),(0.734,0.790,0.912,0.954;1.000)]
C_6	[(0.229,0.273,0.372,0.425;0.500),(0.157,0.230,0.430,0.551;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_7	[(0.192,0.232,0.324,0.375;0.500),(0.126,0.193,0.378,0.495;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]

Table 5.22: Weighted normalized decision-making matrix

1st Level indices (C_i)	Alternatives	Weighted normalized matrix
C_1	A1	[(0.123,0.143,0.259,0.218;0.500),(0.090,0.122,0.225,0.283;1.000)]
	A2	[(0.158,0.181,0.237,0.263;0.500),(0.121,0.157,0.271,0.332;1.000)]
	A3	[(0.055,0.069,0.102,0.119;0.500),(0.035,0.055,0.122,0.165;1.000)]
C_2	A1	[(0.145,0.169,0.217,0.239;0.500),(0.112,0.148,0.246,0.298;1.000)]
	A2	[(0.176,0.202,0.254,0.277;0.500),(0.140,0.180,0.285,0.339;1.000)]
	A3	[(0.058,0.072,0.108,0.126;0.500),(0.037,0.058,0.130,0.176;1.000)]
C_3	A1	[(0.105,0.146,0.197,0.221;0.500),(0.092,0.125,0.229,0.285;1.000)]
	A2	[(0.139,0.190,0.246,0.271;0.500),(0.129,0.166,0.280,0.339;1.000)]
	A3	[(0.056,0.081,0.117,0.135;0.500),(0.044,0.066,0.140,0.184;1.000)]
C_4	A1	[(0.156,0.178,0.237,0.264;0.500),(0.119,0.154,0.272,0.336;1.000)]
	A2	[(0.059,0.073,0.109,0.128;0.500),(0.038,0.058,0.132,0.179;1.000)]
	A3	[(0.118,0.137,0.190,0.215;0.500),(0.085,0.115,0.223,0.283;1.000)]
C_5	A1	[(0.127,0.147,0.200,0.224;0.500),(0.094,0.126,0.232,0.290;1.000)]
	A2	[(0.158,0.182,0.237,0.263;0.500),(0.121,0.158,0.271,0.331;1.000)]
	A3	[(0.059,0.073,0.107,0.125;0.500),(0.038,0.059,0.129,0.173;1.000)]
C_6	A1	[(0.123,0.143,0.193,0.216;0.500),(0.091,0.122,0.223,0.280;1.000)]
	A2	[(0.159,0.182,0.237,0.262;0.500),(0.123,0.158,0.270,0.329;1.000)]
	A3	[(0.051,0.064,0.095,0.112;0.500),(0.032,0.051,0.114,0.155;1.000)]
C_7	A1	[(0.124,0.145,0.199,0.225;0.500),(0.090,0.122,0.233,0.295;1.000)]
	A2	[(0.164,0.188,0.247,0.274;0.500),(0.126,0.164,0.283,0.347;1.000)]
	A3	[(0.046,0.058,0.087,0.103;0.500)(0.028,0.046,0.106,0.146;1.000)]

Table 5.23: Evaluation of alternatives as computed by *Ratio System*

Alternatives	RS_i	$d_{\tilde{\tilde{A}}}$	Ranking order
A1	[(0.902,1.071,1.502,1.606;0.500),(0.688,0.918,1.660,2.066;1.000)]	2.291	2
A2	[(1.014,1.198,1.567,1.737;0.500),(0.798,1.042,1.792,2.196;1.000)]	2.324	1
A3	[(0.443,0.552,0.806,0.936;0.500),(0.299,0.450,0.964,1.282;1.000)]	1.990	3

Table 5.24: Evaluation of alternatives as computed by *Reference Point Approach*

Alternatives	$Max_i\{d(\beta_{ij},\beta_j)\}$	Ranking
A1	0.868	1
A2	0.926	2
A3	0.941	3

Table 5.25: Evaluation of alternatives as computed by *The Full Multiplicative Form* of MULTIMOORA method

Alternatives	y_i	$d_{\tilde{\tilde{A}}}$	Ranking
A1	[(0.0000006,0.0000019,0.0000201,0.0000330;0.5000000),(0.0000001,0.0000006,0.0000416,0.0001927;1.0000000)]	1.75	1
A2	[(0.0000009,0.0000031,0.0000225,0.0000476;0.5000000),](0.0000002,0.0000011,0.0000593,0.0002579;1.0000000)]	1.72	2
A3	[(0.00000000.0000000,0.0000002,0.0000006;0.5000000),(0.0000000,0.0000000,0.0000008,0.0000059;1.0000000)]	1.65	3

Table 5.26: Performance ranking order of agile suppliers according to dominance theory and fuzzy-MULTIMOORA

Alternatives	Ratio System	Reference point	Full Multiplicative form	MULTIMOORA (Final Ranking order)
A1	2	1	1	***1***
A2	1	2	2	***2***
A3	3	3	3	***3***

CHAPTER 6

EXECUTIVE SUMMARY AND CONCLUSIONS

Global market competition, stringent rules-regulations, higher operating costs, scarcity of needful resources and last but of the least, unpredicted demands frequently coming from increasingly informed customer are some of the issues that companies are facing in today's competitive world market. Over the globe, companies are constantly on the lookout for techniques and practices that would enable them to reduce operating costs while increasing market share thereby generating higher profit-margins. As elusive as that goal might seem, numerous manufacturing paradigms have been conceptualized by researchers and practitioners alike who aim to do just that (Nambiar, 2010; Andreeva, 2008; Al-Masoud, 2007; Cruz, 2012).

Agile manufacturing is a conceptual philosophy for the 21st century which helps in making the organization to respond quickly to changing customer demands, maximizing profit in the early stage of product introduction. Mass Customization (MC) is focused on improving the company's capability to manufacture those diverse products through modularity and other advanced techniques. The concept of 'Agility' is essentially the utilization of market-knowledge and virtual cooperation to exploit profitable opportunities in a volatile marketplace.

Agility appraisement has become an important managerial concern in today's highly competitive turbulent business world. Companies are under tremendous pressure due to globalization of business, rapid introduction of newly featured products as well as mass customization. Agility is a conceptual philosophy enhancing speediness, flexibility in manufacturing/production system and increasing responsiveness to face proactively the challenges of dynamic unpredictable customer demands. Adaptation of agile manufacturing and subsequent implementation in appropriate areas may definitely help industries to compete and successfully survive in the competitive market of global economy.

While implementing agility concept in manufacturing, the following questions may definitely arise.

1. How can agility be characterized? Can it be estimated?
2. What are the metrics (dimensions) to be considered towards agility assessment?
3. Is there any relationship amongst agile dimensions? Are they interconnected or logically linked?
4. How can extent (degree) of agility be measured?
5. Is there any standard established agility assessment platform?
6. What are the factors that boost up organizational agility (agility drivers/ providers/ capabilities)?

7. Subsequently, what are the factors those pull behind an organization from becoming agile (agile barriers)?

Within scope and limitation of the present work, the major deliverables (outcome) have been summarized as follows.

ISM is a modelling approach which helps to elucidate and visualize risk interrelationships. Specifically, Interpretive Structural Modelling (ISM) is used to clarify these relationships. ISM is a method which can be applied to a system - such as a network or a society towards better understanding of both direct and indirect relationships among the system's components. ISM is a computer-assisted learning process that enables individuals or groups to develop a map of the complex relationships between the many elements involved in a complex situation.

Factor analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset. Computationally this technique is equivalent to low rank approximation of the matrix of observed variables. Factor Analysis (FA) technique has been utilized in this work through which 41 different agility entities have been reduced into 13 major dimensions like: cross border collaboration, information management agility, product design flexibility, reconfigurability of manufacturing system, agility in institutional framework, production organizing agility, team building agility, customer demand information agility, product design speed, speed of manufacturing, manufacturing flexibility, inter-organization co-ordination and speed of information.

In this thesis, attempts have been made to develop agility appraisement procedural hierarchy both in fuzzy as well as grey context. Due to subjectivity of ill-defined vague evaluation criteria, exploration of fuzzy logic and grey relation theory has been found fruitful in estimating overall supply chain's agility index. Such appraisement modelling may definitely help in value addition to the previous research conducted by the pioneers.

Moreover, exploration of grey numbers and concept of grey-possibility degree (adapted from grey relation theory) in course of agility index evaluation appears to be an important contribution of this dissertation. Existing literature is evident to support the fact that grey theory has never been applied before to estimate agility degree in the context of manufacturing/ production as well as organizational supply chains. However, grey theory provides a practical approach agility appraisement since it considers the condition of fuzziness.

Apart from estimating agility index in industrial supply chain, MC product manufacturing system etc., the work has been extended to identify and analyze ill-performing areas (agile barriers/obstacles) which require future improvement and adequate managerial care to enhance overall organizational agility. As an extension of fuzzy based appraisement module, the concept of fuzzy numbers ranking using ‘maximizing set and minimizing set’ has been found widely utilized in past literatures. In this context, the present thesis proposes the concept of fuzzy ‘Degree of Similarity’ (DOS) as an alternative and effective tool towards identifying existing agile barriers which is a unique contribution deserves mention.

The proposed fuzzy based appraisement module has been case studied with the help of data obtained from two industrial sectors at eastern India (i) Automotive and (ii) Railway construction. It has been found that railway construction appeared more agile in nature in comparison to the automotive sector.

Two MCDM approaches: grey theory and Fuzzy-TOPSIS have been attempted and applied towards benchmarking of alternative MC production systems. The relative advantage as well as disadvantage of aforementioned MCDM techniques has been analyzed too. In contrast to fuzzy-TOPSIS, grey method has been found simpler in computational steps to explore. Evaluating the alternatives and comparing across them, the best practices of the efficient organization can easily be identified and transferred to other organizations. The alternatives can easily be benchmarked and the best agile system can be selected. Benchmarking of alternatives (organizations) helps to make a comparison amongst them and transfer the best practices towards achieving agility. The inefficient organization can follow the peer so identified to improve agility related activities to become more competitive.

It is an important managerial decision to select the particular decision-making group to compute and analyze agility level for a particular organization. In case of benchmarking (of various agile enterprises), the decision-making group bearing same attitude should be utilized. It has been found that the attitude of the decision-makers’ bears significant impact in agility assessment decision-making.

AM organizations are characterized based on innovative alliances between suppliers, customers and manufacturers, agile-enabled technologies, organizational team production and empowerment. In order to support ASCM, effective supplier selection in indeed necessary. However, it seems a challenging task because suppliers are to be assessed based on evaluation criteria, which corresponds to traditional supply chain, along with various agile attributes. In order to avoid inconsistency, imprecision and incompleteness in the decision-makers subjective judgment on qualitative supplier evaluation criteria, a fuzzy based appraisement module has been proposed and proved fruitful in analyzing performance of integrated criteria hierarchy to compute an overall performance index.

In later part of this study, application of Fuzzy-MULTIMOORA has been proposed as an effective mean for evaluating the ranking order of candidate suppliers (benchmarking) and selecting the best one. But the disadvantage of Fuzzy-MULTIMOORA is that this method does not provide any unique performance index with respect to a particular supplier but effective for providing accurate ranking order.

The limitations of the present work have been explained below.

The present work explores different General Hierarchy Criteria (GHC) consisting of agile capabilities (at 1st level), agile attributes (at 2nd level) and agile criterions (at 3rd level) towards development of agility appraisement framework applicable for supply chain, manufacturing sector and MC product manufacturing systems. These criteria-hierarchies have either been selected directly from existing literature or partially adapted and modified further as per experience of the experts. In some cases, integrated criteria-hierarchy has been constructed by accumulating exhaustive listing of various agile indices collected from extensive literature survey. However, the sensitivity of these appraisement platforms (criteria-hierarchies) has not been verified. It has not been examined whether the agile criteria-hierarchy is industry specific or may vary depending upon supply chain architectures as well as functionality. It is felt that a standardized unique criteria-hierarchy is indeed essential to compare as well as benchmark the agile practices and thereby existing agility extent corresponding to different agile enterprises.

Agility appraisement frameworks thus developed here explores decision-makers' subjective evaluation information expressed in terms of linguistic variables. This linguistic evaluation information (expert opinion) has been further transformed into either fuzzy numbers or grey numbers in order to establish a logical mathematical base in analyzing different aspects of agility. The linguistic scales (and corresponding grey/fuzzy representation) utilized in this study have been adapted from the literature itself. However, relative sensitivity of aforementioned scales has not been verified. During agility appraisement in fuzzy environment, linguistic variables have been represented either by Generalized Fuzzy Numbers (GFNs) or Generalized Interval-Valued Fuzzy Numbers (GIVFNs). It is also felt necessary to check which type of fuzzy numbers exploration can provide the most precise and reliable estimation of overall agility index.

In empirical data analysis part of this study, a finite number of decision-makers have been chosen towards assignment of priority weight as well as appropriateness rating against individual agility indices. In practice, the decision-making group (experts) is constructed by the top most managerial level of the enterprise. The expert group may contain selected members coming from different managerial level of the organizational management hierarchy, member from academia, professional management consultants etc. While conducting case studies in Indian automobile sector as well as railway construction; it has been assumed that employees of these organizations have been the decision-makers. Therefore, agility index and corresponding industrial agile scenario that have been interpreted through these case studies has been basically from employees' perspective not from the viewpoint of the top management. Moreover, the optimal number of decision-makers required to effectively participate in a particular decision-making process is obviously a major concern which requires further investigation and subsequent analysis.

Limited case study cannot reveal entire industrial agile scenario of a country. Therefore, extensive case studies need to be conducted with respect to different industries/service sectors towards visualizing real picture of the industrial agile status for the country.

In course of agility appraisement and related decision-making, attempts have been made towards identifying agility barriers. However, necessary actions to be taken (future plan of action) to improve those agility obstructs have not been recommended.

The work can be extended to address aforesaid issues in future research.

BIBLIOGRAPHY

Abo-Sinna MA and Amer AH, Extensions of TOPSIS for multi-objective large-scale nonlinear programming problems, *Applied Mathematics and Computation*, 162 (1) (2005): 243-256.

Abo-Sinna MA, Amer AH and Ibrahim AS, Extensions of TOPSIS for large scale multi-objective non-linear programming problems with block angular structure, *Applied Mathematical Modeling*, 32 (3) (2008): 292-302.

Adrian ECM, Mansoor S and, Colin M, Defining a framework for information systems requirements for agile manufacturing, *International Journal of Production Economics*, 75 (1-2) (2002): 57–68.

Agarwal A and Shankar R, Modeling integration and responsiveness on a supply chain performance: A system dynamics approach, *International Journal System Dynamics and Policy-Making*, 14 (1&2) (2002a): 61–83.

Agarwal A and Shankar R, Analyzing alternatives for improvement in supply chain performance, *Work Study*, 51 (1) (2002b): 32–37.

Agarwal A, Shankar R and Tiwari MK, Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach, *European Journal of Operational Research*, 173 (1) (2006): 211–225.

Agarwal A, Shankar R and Tiwari MK, Modeling agility of supply chain, *Industrial Marketing Management*, 36 (4) (2007): 443–457.

Agility-Forum, Introduction to Agility Workshop, Instructor's Manual, (1994).

Al-Masoud Eng. Hesham, Decision support system for lean, agile and leagile manufacturing, Master’s Thesis, Industrial Engineering Department with the College of Engineering, King Saud University, Riyadh, December 2007.

Ahuja V, Yang J and Shankar R, Benefits of collaborative ICT adoption for building project management, *Construction Innovation*, 9 (3) (2009): 323–340.

Anantatmula V and Kanungo S, Establishing and structuring criteria for measuring knowledge management, *Proceedings of the 38th Hawaii International Conference on System Science (HICSS-38),* January 3-6, (2005), Hilton Waikoloa Village Island of Hawaii (Big Island).

Anatan L, Agile supply chain: Competing through competitive excellence, *SINERGI*, 8 (1) (2006): 13-21.

Andreeva N, Lean production and agile manufacturing-new systems of doing business in the 21st century.

Anuziene L and Bargelis A, Decision-Support System for industrial logistics distribution: cost minimisation applying an agile production approach, *International Journal of Logistics Systems and Management*, 6 (2) (2010): 149- 161.

Arteta BM and Giachetti RE, A measure of agility as the complexity of the enterprise system, *Robotics and Computer-Integrated Manufacturing*, 20 (6) (2004): 495–503.

Audrey Charbonnier-Voirin, The development and partial testing of the psychometric properties of a measurement scale of organizational agility, M@n@gement, 14 (2) (2011): 119-156.

Azevedo SG, Govindanb K, Carvalho H, Cruz-Machado V, An integrated model to assess the leanness and agility of the automotive industry, *Resources, Conservation and Recycling*, 66 (2012): 85–94.

Aziz AKA and Zailani S, A conceptual paper on determinants and outcomes of supply chain agility, *Proceedings of 2011 International Conference on Computer Communication and Management*, IACSIT Press, Singapore.

Baccarach SB, Organisational theories: some criteria for evaluation, *Academy of Management Review*, 14 (4) (1989): 496-515.

Baker P, The design and operation of distribution centers within agile supply chains, *International Journal of Production Economics*, 111 (2008): 27–41.

Baležentis T and Zeng S, Group multi-criteria decision making based upon interval-valued fuzzy numbers: An extension of the MULTIMOORA method, *Expert Systems with Applications*, 40 (2) (2013) 543–550.

Banihashemi SA and Sarani AH, Assessment of organizational agility in cement industry, *African Journal of Business Management*, 6 (27) (2012): 8055-8064.

Baramichai M, Zimmers Jr. EW and Marangos CA, Agile supply chain transformation matrix: an integrated tool for creating an agile enterprise, *Supply Chain Management: an International Journal*, 12 (5) (2007): 334-348.

Baramichai M, Supplier partnership establishment under uncertainties for agile organizations, Ph. D. Thesis, (2007), Lehigh University, USA.

Barrand J, Le Manager agile, Vers un nouveau management pour affronter la turbulence, (2006), Dunod, Paris.

Bavani R, Critical success factors in distributed agile for outsourced product development, *Proceedings of CONSEG 2009, International Conference in Software Engineering*, (2009).

Beriha GS, Patnaik B and Mahapatra SS, Measuring the perception of safety officers on occupational health in Indian industries, *International Journal of Indian Culture and Business Management*, 4 (1) (2011): 30–47.

Bhat BNS, Heuristic algorithm to optimize the manufacturing system design to get maximum profit, *International Journal of Interactive Design in Manufacturing*, 2 (4) (2008):233–243.

Bikker AP and Thompson AGH, Predicting and comparing patient satisfaction in four different modes of health care across a nation, *Social Science and Medicine*, 63 (6) (2006): 1671–1683.

Boer LD, Van der Wegen L and Telgen J, Outranking methods in support of supplier selection, *European Journal of Purchasing Supply Management*, 4 (2-3) (1998): 109-118.

Booth R, Agile manufacturing, *Engineering Management Journal*, 6 (2) (1996): 105–112.

Bottani E, A fuzzy QFD approach to achieve agility, *International Journal of Production Economics*, 119 (2) (2009): 380–391.

Bottani E, Profile and enablers of agile companies: An empirical investigation, *International Journal of Production Economics*, 125 (2) (2010): 251–261.

Boyer KK and McDermott C, Strategic consensus in operation strategy, *Journal of Operations Management*, 17 (1999): 289-305.

Brauers WKM and Zavadskas EK, The MOORA method and its application to privatization in a transition economy, *Control and Cybernetics*, 35 (2) (2006): 445–469.

Brauers WKM and Zavadskas EK, Robustness of the multiobjective MOORA method with a test for the facilities sector, *Technological and Economic Development of Economy: Baltic Journal on Sustainability*, 15 (2) (2009):352–375.

Brauers WKM and Zavadskas EK, Project management by MULTIMOORA as an instrument for transition economies, *Technological and Economic Development of Economy*, 16 (1) (2010): 5–24.

Brauers WKM, Balezˇentis A and Balezˇentis T, MULTIMOORA for the EU Member States updated with fuzzy number theory, *Technological and Economic Development of Economy*, 17 (2) (2011): 259–290.

Brauers WKM and Zavadskas EK, MULTIMOORA optimization used to decide on a bank loan to buy property, *Technological and Economic Development of Economy*, 17 (1) (2011): 174–188.

Breu K, Hemingway CJ, Strathern M and Bridger D, Workforce agility: The new employee strategy for the knowledge economy, *Journal of Information Technology*, 17 (1) (2001): 21-31.

Browne J, Sackett J and Wortmann J, Future manufacturing systems towards the extended enterprise, *Computers in Industry*, 25 (3) (1995): 235–254.

Brown S and Bessant J, The manufacturing strategy – capabilities links in mass customization and agile manufacturing – and exploratory study, *International Journal of Operations and Production Management*, 23 (7) (2003): 707–730.

Bruce M, Daly L and Towers N, Lean or agile: A solution for supply chain management in the textiles and clothing industry, *International Journal of Operations and Production Management*, 24 (2) (2000): 151-170.

Buckley JJ, Fuzzy hierarchical analysis, *Fuzzy Sets and Systems*, 17 (3) (1985): 233–247.

Buffa FP and Jackson WM, A goal programming model for purchase planning, *Journal of Purchasing and Materials Management*, 19 (3) (1983): 27-34.

Bunce P and Gould P, From lean to agile manufacturing, *IEEE Colloquium*, 278 (3) (1996): 1–5.

BüyüKözkan G, Derelİ T and Baykasoğlu A, A survey on the methods and tools of concurrent new product development and agile manufacturing, *Journal of Intelligent Manufacturing*, 15 (6) (2004): 731-751.

Cam-I, Description, modeling and simulation of next generation manufacturing systems, A proposal to the European Commission for an International Intelligent Manufacturing Systems Project No. 95002, (1998).

Campbell DT and Fiske DW, Convergent and discriminant validation by the multitrait-multimethod matrix, *Psychological Bulletin*, 56 (2) (1959): 81-105.

Cao Q and Dowlatshahi S, The impact of alignment between virtual enterprise and information technology on business performance in an agile manufacturing environment, *Journal of Operations Management*, 23 (5) (2005): 531–550.

Carlsona JGH and Yao AC, Simulating an agile, synchronized manufacturing system, *International Journal of Production Economics*, 112 (2) (2008): 714–722.

Carlson R and Turner R, Review of agile case studies for applicability to aircraft systems integration, *Procedia Computer Science*, 16 (2013): 469–474.

Cavugil ST, Yeoh PL, Mitri M, Selecting for eign distributors: an expert systems approach, *Industrial Marketing Management*, 24 (4) (1995): 297–304.

Çebi F and Bayraktar D, An integrated approach for supplier selection, *Logistics Information Management*, 16 (6) (2003): 395-400.

Chakraborty S, Applications of the MOORA method for decision making in manufacturing environment, *International Journal of Advanced Manufacturing Technology*, 54 (9-12) (2011):1155–1166.

Chandna (Kharbanda) R, Measurement of agility in manufacturing systems: a fuzzy logic approach, *Proceedings of the World Congress on Engineering 2008*, Vol. II, (WCE 2008), July 2 - 4, 2008, London, U.K.

Chan FKY and Thong JYL, Acceptance of agile methodologies: A critical review and conceptual framework, *Decision Support Systems*, 46 (4) (2009): 803–814.

Chan FTS, Kumar V and Tiwari M K, The relevance of outsourcing and leagile strategies in performance optimization of an integrated process planning and scheduling model, *International Journal of Production Research*, 47 (1) (2009): 119-142.

Chan FTS and Zhang J, Modelling for agile manufacturing systems, *International Journal of Production Research*, 39 (11) (2001): 2313-2332.

Chang P-L, A fuzzy multi criteria decision making method for technology transfer selection in biotechnology, *Fuzzy Sets and Systems,* 63 (2) (1994): 131-139.

Charan P, Shankar R and Baisya RK, Analysis of interactions among the variables of supply chain performance measurement system implementation, *Business Process Management Journal*, 14 (4) (2008): 512–529.

Charles AW and John RC, A multiobjective approach to vendor selection, *European Journal of Operational Research*, 68 (2) (1993):173 - 184.

Chase Richard B, Jacobs F Robert and Aquilano Nicholas J, *Operations Management for Competitive Advantage (11th Ed.)* (2006). New York: McGraw-Hill/Irwin.

Chaudhry SS, Forst FG and Zydiak JL, Vendor selection with price breaks, *European Journal of Operation Research*, 70 (1) (1993): 52-66.

Chen CT, Extensions of the TOPSIS for group decision-making under fuzzy environment, *Fuzzy Sets and Systems*, 114 (1) (2000): 1–9.

Chen SH, Ranking fuzzy numbers with maximizing set and minimizing set, *Fuzzy Sets and Systems*, 17 (2) (1985): 113-129.

Chen SJ and Hwang CL, *Fuzzy multiple attribute decision making-methods and applications,* (1992), Springer-Verlag, Berlin.

Chen SM, New methods for subjective mental workload assessment and fuzzy risk analysis, *Cyber. Systems: International Journal*, 27 (5) (1996): 449-472.

Chen SJ and Chen SM, A new method for handing multicriteria fuzzy decision-making problems using FN-IOWA operators, *Cybernatics and Systems*, 34 (2) (2003a): 109-137.

Chen SJ and Chen SM, Fuzzy risk analysis based on similarity measures of generalized fuzzy numbers, *IEEE Trans. Fuzzy Systems*, 11 (2003b): 45-56.

Chen S-J, New Similarity measure of generalized fuzzy numbers based on geometric mean averaging operator, *Proceedings of the IEEE International Conference on Fuzzy Systems*, Fuzz-IEEE 2006, Vancouver, Canada.

Chen SM and Chen JH, Fuzzy risk analysis based on ranking generalized fuzzy numbers with different heights and different spreads, *Expert Systems with Applications*, 36 (3) (2009): 6833-6842.

Chen SM and Sanguansat K, Analyzing fuzzy risk based on similarity measures between interval-valued fuzzy numbers, *Expert Systems with Applications*, 38 (7) (2011): 8612–8621.

Chen S-P and Wu W-Y, A systematic procedure to evaluate an automobile manufacturer-distributor partnership, *European Journal of Operational Research*, 205 (3) (2010): 687–698.

Cheng K, Harrison DK and Pan PY, Implementation of agile manufacturing-An AI and Internet based approach, *Journal of Materials Processing Technology*, 76 (1) (1998): 96–101.

Cho H and Jung M, Enabling technologies of agile manufacturing and its related activities in Korea, *Computers and Industrial Engineering*, 30 (3) (1996): 323–334.

Choi TY and Hartley JL, An exploration of supplier selection practices across the supply chain. *Journal of Operations Management,* 14 (4) (1996): 333-343.

Chou S-Y, Dat LQ and Yu VF, A revised method for ranking fuzzy numbers using maximizing set and minimizing set, *Computers and Industrial Engineering*, 61 (4) (2011): 1342–1348.

Choy KL, Lee WB and Lo V, An intelligent supplier management tool for benchmarking suppliers in outsource manufacturing, *Expert Systems with Applications*, 22 (3) (2002): 213-224.

Choy KL, Lee WB and Lo V, Design of a case based intelligent supplier relationship management system - the integration of supplier rating system and product coding system. *Expert Systems with Applications*, 25 (1) (2003): 87-100.

Christopher M, The Agile supply chain competing in volatile markets, *Industrial Marketing Management*, 29 (1) (2000): 37–44.

Christopher M and Towill D, Supply chain migration from lean and functional to agile and customized, *Supply Chain Management*, 5 (4) (2000): 206-213.

Chung SH, Lee AHI and Pearn WL, Analytic network process (ANP) approach for product mix planning in semiconductor fabricator, *International Journal of Production Economics*, 96 (1) (2005): 15-36.

Cook TE and Campbell DT, *Quasi-Experimentation: Design and Analysis Issues for Field Settings*, (1979), Houghton Mifflin, Boston, MA.

Cooper MC and Ellram LM, Characteristics of supply chain management and the implication for purchasing and logistics strategies, *International Journal Logistics Management*, 4 (2) (1993): 13-24.

Cornelis C, Deschrijver G and Kerre EE, Advances and challenges in interval-valued fuzzy logic', *Fuzzy Sets and Systems*, 157 (5) (2006): 622–627.

Costantino N, Dotoli M, Falagario M, Fanti MP, Mangini AM, A model for supply management of agile manufacturing supply chains, *International Journal of Production Economics*, 135 (1) (2012): 451–457.

Cruz Pedro Emanuel Botelho Espadinha da, Lean, Agile, Resilient and Green Supply Chain Management Interoperability Assessment Methodology, Dissertação para obtenção de grau de Mestre em Engenharia e Gestão Industrial (MEGI), Licenciado em Engenharia Química e Biológica – Ramo Química, Maio de 2012.

Dacin MT, Hitt MA and Levitas E, Selecting partners for successful international alliances: Examination of us and Korean firms, *Journal of World Business*, 32 (1) (1997): 3-16.

Daniel V-B, Lucía A and Esteban F, Agility drivers, enablers and outcomes, Empirical test of an integrated agile manufacturing model, *International Journal of Operations and Production Management*, 27 (12) (2007): 1303-1332.

Danuta K-M and Swierczek A, The agile capabilities of Polish companies in the supply chain: An empirical study, *International Journal of Production Economics*, 118 (1) (2009): 217–224.

Das D and Barman D, An AHP framework of supplier evaluation with reference to high-value and critical items: a case study, *International Journal of Services and Operations Management*, 7 (4) (2010): 465-482.

Das C and Tyagi R, Wholesaler: a decision support system for wholesale procurement and distribution, *International Journal of Physical Distribution Logistics Management*, 24 (10) (1994): 4-12.

Davis SM, From "future perfect": Mass customizing, *Strategy and Leadership*, 17 (2) (1989): 16-21.

Debta BR, Patnaik B, Mahapatra SS and Sreekumar, An integrated approach for service quality improvement in medical tourism: an Indian perspective, *International Journal of Services and Operations Management*, 13 (1) (2012): 119–145.

Deng JL, Control problems of grey system,*System and Control Letters*, 1 (5) (1982): 288-294.

Deng JL, The introduction of grey system, *The Journal of Grey System*, 1 (1) (1989): 1-24.

Deng JL, Fundamental methods on grey system, Huazhong University of Science and Technology Publishing, (1996), China.

Deng H, Yeh CH and Willis RJ, Inter-company comparison using modified TOPSIS with objective weights, *Computers and Operations Research*, 27 (10) (2000): 963-973.

Deschamps J-P and Nayak P, Product Juggernauts: How Companies Mobilize to Generate a Stream of Market Winner, (1995), Harvard Business School Press, Boston.

Dimitropoulos GP, Agility index of automatic production system: reconfigurable logic and open source as agility enablers, *Computer in Industry*, 60 (4) (2009): 248–256.

Dulmin R and Mininno V, Supplier selection using a multi-criteria decision aid method, *Journal of Purchasing and Supply Management,* 9 (4) (2003): 177-187.

Dyer JS, Fishburn PC, Steuer RE, Wallenius J and Zionts S, Multiple criteria decision making, multi attribute utility theory: the next ten years, *Management Science*, 38 (5) (1992): 645-654.

Ebiringa OT, Optimal business decision system for multifunctionals: a multifactor analysis of selected manufacturing firms, *Serbian Journal of Management*, 6 (1) (2011): 17–26.

Edmund P, Markus P and Michael AS, International supply chain agility tradeoffs between flexibility and uncertainty, *International Journal of Operations and Production Management*, 21 (5/6) (2001): 823-839.

Elkins DA, Huang N and Alden JM, Agile manufacturing system in the automotive industry, *International Journal of Production Economics*, 91 (3) (2004): 201–214.

Elssamadisy A, Getting Beyond "It Depends!" being specific but not presiptive about agile practice adoption agile journal, (2006).

Erande AS and Verma AK, Measuring Agility of Organizations – A Comprehensive Agility Measurement Tool (CAMT), *Proceedings of The 2008 IAJC-IJME International Conference*, Paper 240, ENT 205.

Ettlie JE, Taking Charge of Manufacturing, (1988), Jossey-Bass, San Francisco.

Faisal MN, Banwet DK and Shankar R, Supply chain agility: analyzing the enablers, *International Journal of Agile Systems and Management*, 2 (1) (2007): 76–91.

Fang GY and Wang YJ, A method for jet fuel suppliers evaluation based on agile supply chain, *Applied Mechanics and Materials*, 26 – 28 (2010): 1083-1087.

Field AP, Factor analysis on SPSS, *Discovering statistics using SPSS*, 2nd Ed. (2005), Sage, London, UK.

Frayret J-M and D'Amours, Montreuil B and Cloutier L, A network approach to operate agile manufacturing systems, *International Journal of Production Economics*, 74 (1-3) (2001): 239-259.

Frohlich M, The implementation of advanced manufacturing technologies: an empirical study of surface mount technology, unpublished DBA Thesis (1998), Boston University, Boston, MA.

Ganguly A, Nilchiani R and Farr JV, Evaluating agility in corporate enterprises, *International Journal of Production Economics,* 118 (2) (2009): 410-423.

Garbie IH, Parsaei HR and Leep HR, A novel approach for measuring agility in manufacturing firms, *International Journal of Computer Applications in Technology*, 32 (2) (2008): 95–103.

Garbie IH, Implementation of Agility Concepts into Oil Industry, *Journal of Service Science and Management*, 4 (2011): 203-214.

Gencer C and Gurpinar D, Analytic network process in supplier selection: a case study in an electronic firm, *Applied Mathematical Modelling*, 31 (11) (2007): 2475–2486.

Ghahremanloo H and Tarokh MJ, An integrated multi agent based model to find the most agile supplier, *Industrial Engineering and Engineering Management (IEEM), 2011 IEEE International Conference* on, 6-9 December 2011.

Ghodsypour SH and O'Brien C, A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming, *International Journal of Production Economics*, 56-57 (1) (1998): 199-212.

Giachetti RE, Martinez LD, Sáenz OA and Chen C-S, Analysis of the structural measures of flexibility and agility using a measurement theoretical framework, *International Journal of Production Economics*, 86 (1) (2003): 47-62.

Goldman SL, Nagel RN and Preiss K, Agile competitors and virtual organizations: Strategies for enriching the customer, (1995), New York: Van Nostrand Reinhold.

Goranson HT, The agile virtual enterprise: cases, metrics, tools, Greenwood Publishing Group, (1999), USA.

Gorvett R and Liu N, Using Interpretive Structural Modeling to identify and quantify interactive risks, *ASTIN Colloquium*, (2007): 1-7, Orlando, FL.

Gorzalczany MB, A method of inference in approximate reasoning based on interval-valued fuzzy sets, *Fuzzy Sets and Systems*, 21 (1) (1987): 1–17.

Gould P, What is agility, *Manufacturing Engineer*, 76 (1) (1997): 28–31.

Grattan-Guinness I, Fuzzy membership mapped onto interval and many-valued quantities, *Z Math Logik Grundlag Mathe*, 22 (1975): 149–160.

Gregory RE, Source selection: a matrix approach, *Journal of Purchase and Materials Management*, 22 (2) (1986): 24-29.

Grimheden ME, Can agile methods enhance mechatronics design education? *Mechatronics*, (2013) doi.org/10.1016/j.mechatronics.2013.01.003.

Groover MP, *Automation, Production Systems, and Computer Integrated Manufacturing*, 2nd Ed., (2001), Prentice Hall.

Grzegorzewski P, Distances between intuitionistic fuzzy sets and/or interval valued fuzzy sets based on the Hausdorff metric, *Fuzzy Sets and Systems*, 148 (2) (2004): 319–328.

Gunasekaran A, Design and implementation of agile manufacturing systems, *International Journal of Production Economics*, 62 (1-2) (1991): 1–6.

Gunasekaran A, Agile manufacturing: Enablers and an implementation framework, *International Journal of Production Research*, 36 (5) (1998): 1223-1247.

Gunasekaran A, Agile manufacturing: A framework for research and development, *International Journal of Production Economics*, 62 (1-2) (1999): 87-105.

Gunasekaran A and Yusuf YY, Agile manufacturing: a taxonomy of strategic and technological imperatives, *International Journal of Production Research*, 40 (6) (2002): 1357-1385.

Gunasekaran A, Lai K and Cheng TCE, Responsive supply chain: A competitive strategy in a networked economy, *Omega*, 36 (4) (2008): 549–564.

Gunasekaran A, Tirtiroglu E and Wolstencroft V, An investigation into the application of agile manufacturing in an aerospace company, *Technovation*, 22 (7) (2002): 405–415.

Hajidimitriou YA and Georgiou AC, A goal programming model for partner selection decisions in international joint ventures, *European Journal of Operational Research*, 138 (3) (2002): 649-662.

Hallgren M and Olhager J, Lean and agile manufacturing: external and internal drivers and performance outcomes, *International Journal of Operations and Production Management*, 29 (10) (2009): 976-999.

Hamel G and Valikangas L, The Quest for Resilience. Harvard Business Review, September (2003): 52–63.

Handfield RS and Melnyk SA, The scientific theory-building process: a primer using the case of TQM, *Journal of Operations Management*, 16 (1998): 321-39.

Harvey MG and Lusch RF, A systematic assessment of potential international strategic alliance partners, *International Business Review*, 4 (2) (1995): 195-212.

Hasan MA, Shankar R and Sarkis J, A study of barriers to agile manufacturing’, *International Journal of Agile Systems and Management*, 2 (1) (2007): 1–22.

Hasan MA, Shankar R and Sarkis J, Supplier selection in an agile manufacturing environment using Data Envelopment Analysis and Analytical Network Process, *International Journal of Logistics Systems and Management*, 4 (5) (2008): 523 - 550.

Hasan MA, Shankar R, Sarkis J, Suhail A and Asif S, A study of enablers of agile manufacturing’, *International Journal of Industrial and Systems Engineering*, 4 (4) (2009): 407–430.

Hayes RH, Wheelwright SC and Clark KB, Dynamic Manufacturing: Creating the Learning Organization, (1988), Free Press, New York.

Herer YT, Tzur M and Yucesan E, Transshipments: an emerging inventory recourse to achieve supply chain leagility, *International Journal of Production Economics*, 80 (3) (2002): 201-212.

Hoda R, Noble J and Marshall S, Developing a grounded theory to explain the practices of self-organizing Agile teams, *Empirical Software Engineering*, 17 (6) (2012): 609-639.

Hoek RI van, Harrison A and Christopher M, Measuring agile capabilities in the supply chain, *International Journal of Operations and Production Management*, 21 (1/2) (2001): 126-147.

Hoak R Van, Mitigating the minefield of pitfalls in creating agile supply chain, International conference of Agility, (2005), Otaniemi, Finland.

Holbrook M, Adventures in complexity, *Academy of Marketing Science Review*, 6 (2003): 1–181.

Holweg M, The genealogy of lean production, *Journal of Operations Management*, 25 (2) (2007): 420–437.

Hsieh CH and Chen SH, Similarity of generalized fuzzy numbers with graded mean integration representation, *Proceedings of 8th International Fuzzy Systems Association World Congress*, Volume 2, Taipei, Taiwan, Republic of China, (1999): 551-555.

Huang CC, Liang WY and Lin SH, An agile approach for supply chain modeling, *Transportation Research Part E*, 45 (3) (2009): 380–397.

Huang YY and Li SJ, How to achieve leagility: A case study of a personal computer original equipment manufacturer in Taiwan, *Journal of Manufacturing Systems*, 29 (2-3) (2010): 63-70.

Hwang CL and Yoon K, Multiple Attribute Decision Making - Methods and Applications: A State-of-the-Art Survey, (1981), Springer-Verlag, Berlin.

Ifandoudas P and Chapman R, A practical approach to achieving agility-a theory of constraints perspective, *Production Planning and Control*, 20 (8) (2009): 691-702.

Inmana RA, Saleb RS, Green Jr. KW and Whitten D, Agile manufacturing: Relation to JIT, operational performance and firm performance, *Journal of Operations Management*, (2010) (In press) doi:10.1016/j.jom.2010.06.001.

Ip WH, Huang M, Yung KL and Wang D, Genetic algorithm solution for a risk-based partner selection problem in a virtual enterprise, *Computers and Operations Research*, 30 (2) (2003): 213-231.

Iskanius P and Helaakoski H, Agility in a project-oriented supply chain, *International Journal of Enterprise Development*, 7 (4) (2009): 358–372.

Ivanov D, Kaeschel J and Sokolov B, Integrated modelling of agile enterprise networks', *International Journal of Agile Systems and Management*, 2 (1) (2007): 23–49.

Jackson M and Johansson C, Agility analysis from a production system perspective, *Integrated Manufacturing Systems*, 14 (6) (2003): 482–488.

Jadidi O, Yusuff RM, Firouzi F and Hong TS, Improvement of a grey based method for supplier selection problem, *Journal of Achievement in Materials and Manufacturing Engineering*, 31 (2) (2008): 770-777.

Jain V and Benyoucef L, New approaches for modeling and evaluating agility in integrated supply Chain, The Way to Flat Organisation, Book edited by: Yanfang Huo and Fu Jia, ISBN 978-953-7619-35-0, pp. 404, December 2008, I-Tech, Vienna, Austria, pp. 237-258.

Jain V, Benyoucef L and Deshmukh SG, A new approach for evaluating agility in supply chains using fuzzy association rules mining, *Engineering Applications of Artificial Intelligence*, 21 (3) (2008): 367-385.

James T, Stepping back from lean [Lean Vs agile manufacturing], *IEE Manufanuring Engineer,* 84 (1) (2005): 16-21.

James-Moore SMR, Agility is easy, but effective agile manufacturing is not, *The Institution of Electrical Engineers (IEE)*, (1997), London WC2R, UK.

Jassbi J, Seyedhosseini SM and Pilevari N, An adaptive neuro fuzzy inference system for supply chain agility evaluation, *International Journal of Industrial Engineering and Production Research*, 20 (4) (2010): 187-196.

Jick TD, Mixing qualitative and quantitative methods: triangulation in action, *Administrative Science Quarterly*, 24 (1979): 602-11.

Johnson RA and Wichern DW, *Applied Multivariate Statistical Analysis*, 5th Ed., Prentice-Hall Inc., (2002), Englewood Cliffs, New York, NY

Jolliffe IT, Principal Component Analysis, Springer Series in Statistics, 2nd Ed., (2002): 1–487, Springer, New York.

Jupp V, The Sage Dictionary of Social Research Methods, Sage Publications, (2006), London.

Kadokawa K, A search for an industrial cluster in Japanese manufacturing sector: evidence from a location survey, *Geo Journal*, (2011), DOI 10.1007/s10708-011-9433-7.

Kahraman C, Evik SC, Ates NY and Gulbay M, Fuzzy multi-criteria evaluation of industrial robotic systems, *Computers and Industrial Engineering*, 52 (4) (2007): 414-433.

Kaiser H, An index of factorial simplicity, *Psychometrik*a, 39 (1) (1974): 31–36.

Karnik NN and Mendel JM, Operations on type-2 fuzzy sets, *Fuzzy Sets and Systems*, 122 (2) (2001): 327–348.

Karuppusami G, Balaji M, Sudhakaran R and Ashwini AC, TADS approach in supply chain agility, *International Journal of Scientific and Engineering Research*, 2 (11) (2011): 1-5.

Kassim NM and Zain M, Assessing the measurement of organizational agility, *The Journal of American Academy of Business*, 4 (1) (2004): 174-177.

Katayama H and Bennett D, Agility, adaptability and leanness: A comparison of concepts and a study of practice, *International Journal of Production Economics*, 60-61 (20) (1999): 43-51.

Kaufmann A and Gupta MM, Introduction to Fuzzy Arithmetic: Theory and Applications, Van Nostrand Reinhold Electrical/Computer Science and Engineering Series, (1991), New York.

Kaveh KD, Mohammad T, Laya O and Feizi K, A hybrid approach based on fuzzy DEA and simulation to measure the efficiency of agility in supply chain: real case of dairy industry, *International Journal of Management Science and Engineering Management*, 6 (3) (2011): 163-172.

Kaveh K-D and Mohammad T, A three-stage fuzzy DEA approach to measure performance of a serial process including JIT practices, agility indices, and goals in supply chains, *International Journal of Services and Operations Management*, 13 (2) (2012): 147-188.

Khorramshahgol R, Azani H and Gousty Y, An integrated approach to project evaluation and selection, *IEEE Transactions on Engineering Manageme*nt, 35 (4) (1988): 265-270.

Kidd PT, *Agile Manufacturing-Forging new frontiers*, (1994), Addison-Wesley, London.

Kidd PT, Agile manufacturing: A strategy for the 21st century, *Agile Manufacturing, IEE Colloquium on* In Agile Manufacturing, IEE Colloquium on (1995), pp. 1/1-1/6, Cheshire Henbury.

Kim K and Park KS, Ranking fuzzy numbers with index of optimism, *Fuzzy Sets and Systems*, 35 (2) (1990): 143–150.

Kim T-Y, Lee S, Kim K and Kim C-H, A modeling framework for agile and interoperable virtual enterprises, *Computers in Industry*, 57 (3) (2006): 204–217.

Kisperska-moron D and Swierczek A, The agile capabilities of Polish companies in the supply chain: an empirical study, *International Journal of Production Economics*, 118 (1) (2009): 217–224.

Klir GJ and Yuan B, Fuzzy Sets and Fuzzy Logic: Theory and Applications, Prentice-Hall Inc., (1995), USA.

Konecka S, Lean and agile supply chain management concepts in the aspect of risk management, *Electronic Scientific Journal of Logistics*, 6 (4) (3) (2010): 24-31.

Krishnamurthy R and Yauch CA, Leagile manufacturing: a proposed corporate infrastructure, *International Journal of Operations and Production Management*, 27 (6) (2007): 588-604.

Kumar A and Motwani J, A methodology for assessing time based competitive advantage of manufacturing firms, *International Journal of Operation and Production Management*, 15 (2) (1995): 36–53.

Kumar A, Singh P, Kaur A and Kaur P, Ranking of generalized trapezoidal fuzzy numbers based on rank, mode, divergence and spread, *Turkish Journal of Fuzzy Systems*, 1 (2) (2010): 141-152.

Kumar P, Shankar R, and Yadav SS, Modeling the enablers of agile manufacturing system, *Proceedings of GLOGIFT*, June 14-16, 2008, Stevens Institute of Technology, Hoboken, NJ, pp. 1-8.

Kumar V, Fantazy KA, Kumar U and Boyle TA, Implementation and management framework for supply chain flexibility, *Journal of Enterprise Information Management*, 19 (3) (2006): 303-319.

Kusiak A and He DW, Design for agility: A scheduling perspective, *Robotics and Computer-Integrated Manufacturing*, 14 (5-6) (1998): 415–427.

Lai YJ, Liu TY and Hwang CL, TOPSIS for MODM, *European Journal of Operational Research*, 76 (3) (1994): 486-500.

Laanti M, Salo O and Abrahamsson P, Agile methods rapidly replacing traditional methods at Nokia: A survey of opinions on agile transformation, *Information and Software Technology*, 53 (3) (2011): 276–290.

Lee CKM, Lau HCW, Yu KM and Fung RYK, Development of a dynamic data interchange scheme to support product design in agile manufacturing, *International Journal of Production Economics*, 87 (3) (2004): 295–308.

Lee GH, Designs of components and manufacturing systems for agile manufacturing, *International Journal of Production Research*, 36 (4) (1998): 1023-1044.

Lee WB and Lau HCW, Factory on demand: The shaping of an agile network, *International Journal of Agile Manufacturing Systems*, 1/2 (1999): 83–87.

Lee Y and Lee H, Application of factor analysis for service R&D classification: a case study on the Korean ICT industry, *Expert Systems with Applications*, 38 (3) (2011): 2119–2124.

Leonard-Barton D, A dual methodology for case studies: synergistic use of a longitudinal single site with replicated multiple sites, *Organisation Science*, 15 (1990): 271-92.

Li CC, Fun YP and Hung JS, A new measure for supplier performance evaluation, *IEE Transaction Operation Engineering*, 29 (9) (1997): 753-758.

Li G-D, Daisuke Y and Nagai M, A grey-based decision-making approach to the supplier selection problem, *Mathematical and computer modeling*, 46 (3-4) (2007): 573-581.

Li G-D, Yamaguchi D and Nagai M, Application of grey-based rough decision-making approach to suppliers selection, *Journal of Modelling in Management*, 2 (2) (2007): 131-142.

Li G-D, Yamaguchi D and Nagai M, A grey-based rough decision-making approach to supplier selection, *International Journal of Advanced Manufacturing Technology*, 36 (9) (2010): 1032–1040.

Li J-H, Alistair RA and Richard TH, The evolution of agile manufacturing, *Business Process Management Journal*, 9 (2) (2003): 170 – 189.

Li W, Li P and Rong Y, Case-based agile fixture design, *Journal of Materials Processing Technology*, 128 (1-3) (2002): 7–18.

Liou TS and Wang MJ, Ranking fuzzy numbers with integral value, *Fuzzy Sets and Systems*, 50 (3) (1992): 247–255.

Lin CR and Chen HS, A fuzzy strategic alliance selection framework for supply chain partnering under limited evaluation resources. *Computers in Industry,* 55 (2) (2004): 159-179.

Lin CT, Chiu H and Chu PY, Agility index in the supply chain, *International Journal of Production Economics*, 100 (2) (2006a): 285-299.

Lin CT, Chiu H and Tseung YH, Agility evaluation using fuzzy logic, *International Journal of Production Economics*, 101 (2) (2006b): 353–368.

Lin M, Vender selection and evaluation model in supply chain venture management, *Decision and Reference*, 169 (1) (2004): 43-44.

Liu P, A weighted aggregation operators multi-attribute group decision making method based on interval-valued trapezoidal fuzzy numbers, *Expert Systems with Applications*, 38 (1) (2011a): 1053–1060.

Liu P, An extended TOPSIS method for multiple attribute group decision making based on generalized interval-valued trapezoidal fuzzy numbers, *Informatica*, 35 (2) (2011b): 185–196.

Liu P and Jin F, A multi-attribute group decision-making method based on weighted geometric operators of interval-valued trapezoidal fuzzy numbers, *Applied Mathematical Modeling*, 36 (6): (2012): 2498–2509.

Liu P and Wang M, An extended VIKOR method for multiple attribute group decision making based on generalized interval-valued trapezoidal fuzzy numbers, *Scientific Research and Essays*, 6 (4) (2011): 766-776.

Liu X, Fan Z, Li Q and Ji X, The study on customer-driven agile manufacturing system and its implementation for iron and steel enterprise, 01/2004; In proceeding of the *2004 International Conference on Computer and Information Technology (CIT 2004)*, 14-16 September 2004, Wuhan, China.

Long C, Measuring your strategic agility: A checklist, *Consulting to Management*, 11 (3) (2000): 25-28.

Lorange P, Roos J and Bronn PS, Building successful strategic alliances, *Long Range Planning*, 25 (6) (1992): 10-18.

Lou P, Chen Y, Zhou Z and Yuan C, An AHP/DEA method for vendor selection in the agile supply chain, *Journal of Huazhong University of Science and Technology*, 30 (4) (2002): 29-31.

Luo X, Wu C, Rosenberg D and Barnes D, Supplier selection in agile supply chains: An information-processing model and an illustration, *Journal of Purchasing and Supply Management*, 15 (4) (2009): 249–262.

Luo Y, Joint venture success in china: How should we select a good partner? *Journal of World Business*, 33 (2) (1998): 145-166.

Lyu Jr J, CALS: an enabling strategy for agile management Systems, *International Journal of Agile Management Systems*, 1 (1) (1999): 41-44.

Mahdiloo M, Noorizadeh A and Saen RF, Suppliers ranking by cross-efficiency evaluation in the presence of volume discount offers, *International Journal of Services and Operations Management*, 11 (3) (2012): 237-254.

Mandal A and Deshmukh SG, Vendor selection using interpretive structural modeling, *International Journal of Operations and Production Management*, 14 (6) (1994): 52–59.

Mansouri Mo, Ganguly A and Mostashari A, Evaluating agility in extended enterprise systems: A transportation network case, *American Journal of Engineering and Applied Sciences*, 4 (1) (2011): 142-152.

Markland R, Vickery SK and Davis RA, Operation management: concepts in manufacturing and services, (1995), New York: West Publishing Company.

Mashayekhi AN, Eshlaghy AT, Rajabzadeh A and Razavian MM, Determination constructs validity of an agile organization model by using factor analysis, *International Journal of Industrial Engineering*, 7 (14) (2011): 75–89.

Maskell B, The age of agile Manufacturing, *Supply Chain Management: an International Journal*, 6 (1) (2001): 5-11.

Mason-Jones R, Naylor B and Towill DR, Engineering the leagile supply chain, *International Journal of Agile Management Systems*, 2 (1) (2000a): 54-61.

Mason-Jones R, Naylor B and Towill DR, Lean, agile or leagile? Matching your supply chain to the marketplace, *International Journal of Production Research*, 38 (17), (2000b): 4061-4070.

Masson R, Iosif L, MacKerron G and Fernie J, Managing complexity in agile global fashion industry supply chains, *International Journal of Logistics Management*, 18 (2) (2007): 238–254.

Matt DT, Functional periodicity as a concept for the (re-)design to agility of production systems, *Production Engineering Research and Development*, 4 (4) (2010):363–369.

McCutcheon D and Meredith J, Conducting case study research in operations management, *Journal of Operations Management*, 16 (1993): 441-54.

McLachlin R, Management initiatives and just-in-time manufacturing, *Journal of Operations Management*, 15 (1997): 271-92.

Meredith J, Building operations management theory through case and field research, *Journal of Operations Management*, 16 (1998): 441-54.

Meredith S and Francis D, Journey towards agility: the agile wheel explored, *The TQM Magazine*, 12 (2) (2000): 137-143.

Mikhailov L, Fuzzy analytical approach to partnership selection in formation of virtual enterprises, *Omega*, 30 (5) (2002): 393-401.

Mishra S, Samantra C, Datta S and Mahapatra SS, Multi-attribute group decision-making (MAGDM) for supplier selection using fuzzy linguistic modelling integrated with VIKOR method, *International Journal of Services and Operations Management*, 12 (1) (2012): 67 – 89.

Misra SC, Kumar V and Kumar U, Identifying some important success factors in adopting agile software development practices, *The Journal of Systems and Software*, 82 (11) (2009): 1869–1890.

Meza' JC, Moen CD, Plantenga TD, Spence PA, Tong CH, Hendrickson BA, Leland RW and Reese GM, Sandia Report, SAND97-8275 UC-406, Unlimited Release, Printed August 1997.

Moeinzadeh P and Hajfathaliha A, A combined fuzzy decision making approach to supply chain risk assessment, *International Journal of Human and Social Sciences*, 5 (13) (2010): 859-875.

Monczka RM and Trecha SJ, Cost-based supplier performance evaluation, *Journal of purchasing and Material Management*, 24 (2) (1998): 2-7.

Moore RE, Interval Analysis, Prentice-Hall, Englewood Cliffs, (1966), New Jersey.

Moore SMR, Agility is easy, but effective agile manufacturing is not, *IEEE Colloquium on Agile Manufacturing*, (1995): 3/1–3/4, DOI: 10.1049/ic:19951099.

Moron DK and Haan J, Improving supply chain performance to satisfy final customers: Leagile experiences of a polish distributor, *International Journal of Production Economics*, 133 (1) (2011): 127-134.

Motadel M, Toloie-Eshlaghy A and Halvachi-Zadeh D, Assessment of supply chain agility in the automotive industry of Tehran, *European Journal of Scientific Research*, 61 (2) (2011): 210-229.

Mukherjee A, Mitchell W and Talbot FB, The impact of new manufacturing technologies and strategically flexible production, *Journal of Operations Management*, 18 (2000): 139-68.

Nagel RN, Dove R, Goldman S and Preiss K, 21st century manufacturing enterprise strategy: an industry-led view, Iacocca Institute, Lehigh University, (1991), Bethlehem, PA.

Narasimhan R, Talluri S and Mahapatra SK, Multiproduct, multi-criteria model for supplier selection with product life-cycle considerations, *Decision Sciences,* 37 (4) (2006a): 577-603.

Narasimhan R, Swink M and Kim SW, Disentangling leanness and agility: An empirical investigation, *Journal of Operations Management*, 24 (5) (2006b): 440–457.

Nambiar AN, Modern manufacturing paradigms-A comparison, *Proceedings of the International MultiConference of Engineers and Computer Scientists 2010 Vol. III*, (IMECS 2010), March 17-19, 2010 Hong Kong.

Nasr Emad S Abouel, Osman Mohammed I, Eng. Soha R Elatty, Measuring agility index using system flexibility and response, POMS 22nd Annual Conference, Reno, Nevada, U.S.A., April 29 to May 2, 2011.

Naylor JB, Naim MM and Berry D, Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain, *International Journal of Production Economics*, 62 (1-2) (1999): 107-118.

Nazar Dahmardeh, Seyyed Ali Banihashemi, Organizatinal Agility and Agile Manufacturing, European Journal of Economics, *Finance and Administrative Sciences*, 27 (2010): 178-184.

Negi DS, Fuzzy analysis and optimization, Ph.D. Dissertation (1989), Department of Industrial Engineering, Kansas State University.

Ngai EWT, Cheng TCE and Ho SSM, Critical success factors of web-based supply-chain management systems an exploratory study, *Production Planning and Control,* 15 (6) (2004): 622-630.

Nunnally JC, *Psychometric Theory*, McGraw-Hill, Englewood Cliffs, (1988), New York, NY.

Ocal EM, Oral EL, Erdis E and Vural G, Industry financial ratios – application of factor analysis in Turkish construction industry, *Building and Environment*, 42 (1) (2007): 385–392.

Othman A and Owen L, The multidimensionality of CARTER model to measure customer service quality (SQ) in Islamic banking industry: a study in Kuwait financial house, *International Journal of Islamic Financial Service*, 3 (4) (2001): 1–12.

Pagell M and Krause DR, A multiple-method study of environmental uncertainty and manufacturing flexibility, *Journal of Operations Management*, 17 (1999): 307-25.

Pan AC, Allocation of order quantities among suppliers, *Journal of Purchasing Material Management*, 25 (3) (1989): 36-39.

Pan F and Nagi R, Multi-echelon supply chain network design in agile manufacturing, *Omega*, 41 (6) (2013): 969–983.

Parasuraman A, Grewal D and Krishnan R, *Marketing Research*, Houghton Mifflin Company, (2004), Boston, New York.

Petersen K and Wohlin C, Comparison of issues and advantages in agile and incremental development between state of the art and an industrial case, *The Journal of Systems and Software*, 82 (9) (2009): 1479–1490.

Pham DT, Ebrahim Z, Shamsuddin T, Barton R and Williams O, The relationship between lean manufacturing agile manufacturing and sustainability, *Innovative Production Machines and Systems (I'PROMS '08)*, (2008), Cardiff University.

Poolton J, Ismail HS, Reid IR and Arokiam IC, Implementation of an agile marketing approach for the manufacturing-based SME, *International Journal of Entrepreneurship and Small Business*, 6 (2) (2008): 264–279.

Powell WW, Neither market nor hierarchy: Network forms of organization, *Research in Organizational Behavior*, 12 (1990): 295-336.

Power DJ, Sohal AS, Rahman S, Critical success factors in agile supply chain management: An empirical study, *International Journal of Physical Distribution and Logistics Management*, 31 (4) (2001): 247-265.

Prater M, Biehl M and Smith M, International supply chain agility – tradeoffs between flexibility and uncertainty, *International Journal of Operations and Production Management,* 21 (5–6) (2001): 823–839.

Prince J and Kay JM, Combining lean and agile characteristics: Creation of virtual groups by enhanced production flow analysis, *International Journal of Production Economics*, 85 (3) (2003): 305-318.

Qumer A and Henderson-Sellers B, An evaluation of the degree of agility in six agile methods and its applicability for method engineering, *Information and Software Technology*, 50 (4) (2008): 280-295.

Qureshi MN, Kumar P and Kumar D, Selection of Logistics Services Provider (LSP) under fuzzy environment: a graph-theoretic and matrix approach, *International Journal of Logistics Systems and Management*, 5 (5) (2009): 551- 573.

Rachel M-J and Denis R-T, Total cycle time compression and the agile supply chain, *International Journal of Production Economics*, 62 (1) (1999): 61-73.

Rad DR, Amiri M, Gardeshi M and Moradi JS, Application of factor analysis for agile supply chain classification: a case study on the Iranian automotive parts supplier (SAPKO), *Management Science*, 1 (4) (2011): 457–466.

Radfar R, Pilevari N and Aflaki S, A model for evaluating and comparing the agility of supply chain case study: Iran Telecommunication Company and Irancell Company, *American Journal of Scientific Research*, 1 (33) (2011): 127-135.

Rahiminia F, Moghadasian M and Castka P, Benchmarking legality in services: the case study of a fast food restaurant chains in Iran, *Benchmarking: an International Journal*, 16 (6) (2009): 799–816.

Rahimnia F and Moghadasian M, Supply chain leagility in professional services: how to apply decoupling point concept in healthcare delivery system, *Supply Chain Management: An International Journal*, 15 (1) (2010): 80-91.

Ramesh A, Banwet DK and Shankar R, Modelling the enablers of supply chain collaboration, *International Journal of Logistics Systems and Management*, 4 (6) (1998): 617–633.

Ramesh G and Devadasan SR, Literature review on the agile manufacturing criteria, *Journal of Manufacturing Technology Management*, 18 (2) (2007): 182-201.

Raut RD, Bhasin HV, Kamble SS and Banerjee S, An integrated fuzzy-AHP-LP (FAHLP) approach for supplier selection and purchasing decisions, *International Journal of Services and Operations Management*, 10 (4) (2011): 400-425.

Reed K and Blunsdon B, Organizational flexibility in Australia, *International Journal of Human Resource Management*, 9 (3) (1998): 457–477.

Ren J, Yusuf YY and Burns ND, A prototype of measurement system for agile enterprise, *International Conference on Quality, Reliability, and Maintenance*, Oxford, UK, (2000): 247–252.

Ren J, Yusuf YY and Burns ND, The effects of agile attributes on competitive priorities: a neural network approach, *Integrated Manufacturing Systems*, 14 (6) (2003): 489-497.

Ren J, Yusuf YY and Burns ND, A decision-support framework for agile enterprise partnering, *International Journal of Advanced Manufacturing Technology*, 41 (1-2) (2009): 180-192.

Richards CW, Agile manufacturing: beyond lean? *Production and Inventory Management Journal*, 37 (2) (1996): 60–64.

Richard D, Robert G and John JM, Agile manufacturing research: accomplishments and opportunities, *IIE Transactions*, 29 (10) (1997): 813-823.

Robertson M and Jones C, Application of lean production and agile manufacturing concepts in a telecommunications environment, *International Journal of Agile Management Systems*, 1 (1) (1999): 14-16.

Rosenthal EC, Zydiak JL and Chaudhry SS, Vendor selection with bundling, *Decision Science*, 26 (1) (1995): 35-48.

Saisse MCP and Wilding RD, Short-term strategic management in mass customized markets, *Logistics Information Management*, 10 (5) (1997): 199–207.

Sambuc R, Fonctions f-floues. Application a` l'aide au diagnostic en pathologie thyroidienne. Ph. D. Thesis, (1975), University of Marseille.

Sanchez LM and Nagi R, A review of agile manufacturing systems, *International Journal of Production Research*, 39 (16) (2001): 3561-3600.

Sandeep M, Kumanan S and Vinodh S, Application of fuzzy SMART approach for supplier selection, *International Journal of Services and Operations Management*, 9 (3) (2011): 365-388.

Sarkar A and Mohapatra PKJ, Evaluation of supplier capability and performance: A method for supply base reduction, *Journal of Purchasing and Supply Management,* 12 (3) (2006), 148-163.

Sarkis J and Talluri S, A model for strategic supplier selection*, Ninth International Conference on IPSERA*, (2000): 652-661.

Sarkis J, Benchmarking for agility, *Benchmarking: an International Journal*, 8 (2) (2002): 88 – 107.

Saxena JP, Sushil and Vrat P, Scenario building: a critical study of energy conservation in the Indian cement industry, *Technological Forecasting and Social Change*, 41 (2) (1992): 121–146.

Seyedhoseini SM, Jassbi J and Pilevari N, Application of adaptive neuro fuzzy inference system in measurement of supply chain agility: Real case study of a manufacturing company, *African Journal of Business Management*, 4 (1) (2010): 083-096.

Shafer RA, Creating organizational agility: The human resource dimension, Unpublished Ph.D. dissertation (1997), Cornell University.

Shahrabi B, The Agility Assessment Using Fuzzy Logic, *World Applied Sciences Journal*, 13 (5) (2011): 1112-1119.

Shahraki A, Yaghoobi NM and Fard SG, Fuzzy evaluation to reach the required agility at manufacturing organizations, *Journal of Basic Application Science*, 1 (9) (2011): 1112–1123.

Sharifi H and Zhang Z, A methodology for achieving agility in manufacturing organizations: An introduction, *International Journal of Production Economics*, 62 (1-2) (1999): 7-22.

Sharifi H and Zhang Z, A methodology for achieving agility in manufacturing organizations, *International Journal of Operation and Production Management*, 20 (4) (2000): 496–512.

Sharifi H and Zhang Z, Agile manufacturing in practice: Application of a methodology, *International Journal of Operations and Production Management*, 21 (5/6) (2001): 772-794.

Sharifi H, Colquhoun G, Barclay I and Dann Z, Agile manufacturing: a management and operational framework, *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture*, 215 (6) (2001): 857–869.

Sharma HD, Gupta AD and Sushil, The objective of waste management in India: a futures enquiry, *Technological Forecasting and Social Change*, 48 (3) (1995): 285–309.

Sharp JM, Irani Z and Desai S, Working towards agile manufacturing in the UK industry, *International Journal of Production Economics*, 62 (1-2) (1999): 155–169.

Sherehiy B, Karwowski W and Layer JK, A review of enterprise agility: Concepts, frameworks, and attributes, *International Journal of Industrial Ergonomics*, 37 (5) (2007): 445–460.

Shi JR, Liu SY and Xiong WT, A new solution for interval number linear programming, *Journal of Systems Engineering Theory and Practice*, 25 (2) (2005): 101-106.

Shih Y-C and Lin C-T, Agility index of manufacturing firm -A fuzzy-logic-based approach, 0-7803-7385-5/02/$17.00 02002 IEEE, (2002): 465-470.

Sidky A, Arthur J and Bohner S, A disciplined approach to adopting agile practices: The agile adoption framework, *Innovations Systems and Software Engineering*, 3 (3) (2007):203–216.

Silverira GD, Borenstein D and Fogliatto FS, Mass customization: Literature review and research directions, *International Journal of Production Economics*, 72 (1) (2001): 1-13.

Singh RK, Kumar P and Gupta V, Fuzzy statistical approach for vendor selection in Supply Chain, *International Journal of Logistics Systems and Management*, 7 (3) (2010): 286-301.

Smytka DL and Clemens MW, Total cost supplier selection model: a case study, *International Journal of Purchasing and Materials Management*, 29 (1) (1993): 42-49.

Somuyiwa AO, Adebayo IT and Akanbi TA, Supply chain performance: An agile supply chain driven by information system (Is) capabilities, *British Journal of Arts and Social Sciences*, 1 (2) (2011): 125-135.

Song M, Fu R, Zhu C, Xin Z, Study on the agile supply chain management based on agent, *The Journal of China Universities of Posts and Telecommunications*, 14 (1) (2007): 115-118.

Soni G and Kodali P, Evaluating reliability and validity of lean, agile and leagile supply chain constructs in Indian manufacturing industry, *Production Planning and Control*, 23 (10-11) (2012): 864-884.

Soukup WR, Supplier selection strategies, *International Journal of Purchasing and Material Management*, 23 (3) (1987): 7-12.

Sridevi B and Nadarajan R, Fuzzy similarity measure for generalized fuzzy numbers, *International Journal of Open Problems in Computer Science and Mathematics*, 2 (2) (2009): 240-253.

Stacey R, Griffin D and Shaw P, Complexity and Management: Fad or Radical Challenge to Systems Thinking? (2000), London: Routledge.

Storey J, Emberson C and Reade D, The barriers to customer responsive supply chain management, *International Journal of Operations and Production Management*, 25 (3) (2005): 242–260.

Stratton R and Warburton RDH, The strategic integration of agile and lean supply, *International Journal of Production Economics*, 85 (2) (2003): 183-198.

Stuart I, McCutcheon D, Handfield R, McLachlin R and Samson D, Effective case research in operations management: a process perspective, *Journal of Operations Management*, 20 (5) (2002): 419-433.

Sukati I, Hamid AB, Baharun R, Yusoff RM, Anuar MA, The effect of organizational practices on supply chain agility: An empirical investigation on Malaysia manufacturing industry, *Procedia-Social and Behavioral Sciences*, 40 (2012): 274–281.

Subasic P and Hirota K, Similarity rules and gradual rules for analogical and interpolative reasoning with imprecise data, *Fuzzy Sets Systems*, 96 (1) (1998): 53-75.

Swafford PM, Ghosh S and Murthy NN, The antecedents of supply chain agility of a firm: scale development and model testing, *Journal of Operations Management*, 24 (2) (2006a): 170-188.

Swafford PM, Ghosh S, Murthy N, A frame work for assessing value chain agility, *International Journal of Operation Production Management*, 26 (2) (2006b): 118-140.

Talluri S, Baker RC and Sarkis J, A framework for designing efficient value chain networks. *International Journal of Production Economics*, 62 (1) (1999): 133-144.

Talluri S, A buyer-seller game model for selection and negotiation of purchasing bids, *European Journal of Operational Research*, 143 (1) (2002): 171–180.

Thompson K, Vendor profile analysis, *Journal of Purchasing and Materials Management*, 26 (1) (1990): 11-18.

Timmerman E, An approach to vendor performance evaluation, *Journal of Purchasing and Materials Management*, 22 (4) (1986): 1-7.

Tsai C-S, Chen C-W, Lin C-T, Align Agile Drivers, Capabilities and Providers to Achieve Agility: a Fuzzy-Logic QFD Approach, Supply Chain, Theory and Applications, Book edited by: Vedran Kordic, ISBN 978-3-902613-22-6, pp. 558, February 2008, I-Tech Education and Publishing, Vienna, Austria.

Tseng Y-H. and Lin C-T, Enhancing enterprise agility by deploying agile drivers, capabilities and providers, *Information Sciences*, 181 (17) (2011): 3693–3708.

Tsourveloudis N, On the Measurement of Agility in Manufacturing Systems, *CD-ROM Proceedings of the European Symposium on Intelligent Techniques (ESIT'99)*, (1999), Athens, Greece.

Tsourveloudis NC and Valavanis KP, On the measurement of enterprise agility, *Journal of Intelligent and Robotic Systems*, 33 (3) (2002): 329–342.

Tziakas DN, Chalikias GK, Kaski JC, Kekes A, Hatzinikolaou EI, Stakos DA, Tentes IK, Kortsaris AX and Hatseras DI, Inflammatory and anti-inflammatory variable clusters and risk prediction in acute coronary syndrome patients: a factor analysis approach, *Atherosclerosis*, 193 (1) (2007): 196–203.

Van De Ven AH, Nothing is quite as practical as a good theory, *Academy of Management Review*, 14 (4) (1989): 486-495.

Vinodh S, Sundararaj G, Devadasan SR and Rajanayagam D, Quantification of agility: an experimentation in an Indian electronics switches manufacturing company, *Journal of Engineering Design and Technology*, 6 (1) (2008): 48–64.

Vinodh S, Sundararaj G, Devadasan SR and Rajanayagam D, TADS-ABC: a system for costing total agile design system, *International Journal of Production Research*, 47 (24) (2009): 6941–6966.

Vinodh S, Devadasan SR, Reddy BV and Ravichanda K, Agility index measurement using multi-grade fuzzy approach integrated in a 20 criteria agile model, *International Journal of Production Research*, 48 (23) (2010a): 7159-7176.

Vinodh S, Sundararaj G and Devadasan SR, Measuring organisational agility before and after implementation of TADS, *International Journal of Advanced Manufacturing Technology*, 47 (5-8) (2010b): 809–818.

Vinodh S, Gautham SG, Ramiya RA and Rajanayagam D, Application of fuzzy analytic network process for agile concept selection in a manufacturing organization, *International Journal of Production Research*, 48 (24) (2010c): 1-22.

Vinodh S, Devadasan SR, Reddy BV and Ravichand K, Agility index measurement using multi-grade fuzzy approach integrated in a 20 criteria agile model, *International Journal of Production Research*, 48 (23) (2010d): 7159–7176.

Vinodh S and Devadasan SR, Twenty criteria based agility assessment using fuzzy logic approach, *International Journal of Advanced Manufacturing Technology*, 54 (9-12) (2011): 1219–1231.

Vinodh S, Madhyasta UR and Praveen T, Scoring and multi-grade fuzzy assessment of agility in an Indian electric automotive car manufacturing organisation, *International Journal of Production Research*, (2011), DOI:10.1080/00207543.2010.543179.

Vinodh S, Kumar VU and Girubha RJ, Thirty-criteria-based agility assessment: a case study in an Indian pump manufacturing organization, *International Journal of Advanced Manufacturing Technology*, (2012), DOI 10.1007/s00170-012-3988-4.

Vinodh S, Varadharajan AR, Subramanian A, Application of fuzzy VIKOR for concept selection in an agile environment, *The International Journal of Advanced Manufacturing Technology*, 65 (5-8) (2013): 825-832.

Vivek SD, Banwet DK and Shankar R, Analysis of interactions among core, transaction and relationship-specific investments: the case of offshoring, *International Journal of Operations Management*, 26 (2) (2008): 180–197.

Voss CA, Tsikriktsis N and Frohlich M, Case research in operations management, *International Journal of Operations and Production Management*, 22 (2) (2002): 195-219.

Wacker JG, A definition of theory: research guidelines for different theory building research methods in operations management, *Journal of Operations Management*, 16 (1998): 361-85.

Wad P, The automobile industry of Southeast Asia: Malaysia and Thailand, *Journal of Asia Pacific Economy*, 14 (2) (2009): 172–193.

Wadhwa S, Mishra M and Saxena A, A network approach for modeling and design of agile supply chains using a flexibility construct, *International Journal of Flexible Manufacturing System*, 19 (4) (2007): 410–442.

Wang G and Li X, The applications of interval-valued fuzzy numbers and interval-distribution numbers, *Fuzzy Sets and Systems*, 98 (3) (1998): 331–335.

Wang G and Li X, Correlation and information energy of interval valued fuzzy numbers, *Fuzzy Sets and Systems*, 103 (1) (2001): 169-175.

Wang GH, Wang YX and Zhao T, Analysis of interactions among the barriers to energy saving in China, *Energy Policy*, 36 (6) (2008): 1879–1889.

Wan J and Wang R, Empirical research on critical success factors of agile software process improvement, *Journal of Software Engineering and Applications*, 3 (2010): 1131-1140.

Wang R-T, IIo C-T, Feng C-M and Yang Y-K, A comparative analysis of the operational performance of Taiwan's major airports, *Journal of Air Transport Management*, 10 (5) (2004): 353-360.

Wang TC and Chang TH, Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment, *Expert Systems with Applications*, 33 (4) (2007): 870–880.

Wang W-P, Towards developing agility evaluation of mass customization systems using 2-tuple linguistic computing, *Expert Systems with Applications*, 36 (2) (2009): 3439–3447.

Wang X, Conboy K and Cawley O, “Leagile” software development: An experience report analysis of the application of lean approaches in agile software development, *Journal of Systems and Software*, 85 (6) (2012): 1287–1299.

Wang YM and Luo Y, Area ranking of fuzzy numbers based on positive and negative ideal points, *Computers and Mathematics with Applications*, 58 (9) (2009): 1769–1779.

Wanyu Z, Dan L and Jin Z, A Comprehensive Method for Agility Evaluation of Dynamic Alliance based on Certainty Factor and Fuzzy Logic, Proceedings of the IEEE International Conference on Mechatronics and Automation, Niagara Falls, Canada, July 2005.

Ward C, What is agility, *Industrial Engineering*, 26 (11) (1994): 14–15.

Warfield JN, Intent structures, *IEEE Transactions on Systems, Man, and Cybernetics*, 3 (2) (1973): 133–140.

Warfield JN, *Societal Systems: Planning, Policy and Complexity*, John Wiley and Sons Inc., (1976), New York.

Weber CA and Current JR, A multi-objective approach to vendor selection, *European Journal of Operation Research*, 68 (2) (1993): 173-184.

Wei S-H and Chen S-M, Fuzzy risk analysis based on interval-valued fuzzy numbers, *Expert Systems with Applications*, 36 (2) (2009): 2285-2299.

Willis TH, Huston CR and Pohlkamp F, Evaluation measures of just-in-time supplier performance, *Production and Inventory Management Journal*, 34 (2) (1993): 1-5.

Wilson S and Platts K, How do companies achieve mix flexibility? *International Journal of Operations and Production Management*, 30 (9) (2010): 978-1003.

Womack, James P. Machine that changed the world. Scribner, (1990).

Wu C and Barnes D, *Four-phase conceptual model for supplier selection in agile supply chains,* Working Paper Series (2008), SoMWP-0808, School of Management, Royal Holloway University of London.

Wu C and Barnes D, *A model for continuous improvement in supplier selection in agile supply chains, Knowledge and Process Management: The Journal of Corporate Transportation*, 16 (3) (2009): 85-110.

Wu C and Barnes D, Rosenberg D and Luo X, An analytic network process-mixed integer multi-objective programming model for partner selection in agile supply chains, *Production Planning and Control: The Management of Operations*, 20 (3) (2009): 254-275.

Wu C and Barnes D, Formulating partner selection criteria for agile supply chains: A Dempster–Shafer belief acceptability optimization approach, *International Journal of Production Economics*, 125 (2) (2010): 284–293.

Wu C and Barnes D, A literature review of decision-making models and approaches for partner selection in agile supply chains, *Journal of Purchasing and Supply Management*, 17 (4) (2011): 256–274.

Wu C and Barnes D, A dynamic feedback model for partner selection in agile supply chains, *International Journal of Operations and Production Management*, 32 (1) (2012): 79 – 103.

Wu JJ, Liu G and Xi CY, The study on agile supply chain-based supplier selection and evaluation, *Information Science and Engineering, 2008 (ISISE' 08)*, International Symposium on during 20-22 December 2008.

Xia J, Grey system theory to hydrology, Huazhong University of Science and Technology Press, (2000), Hubei, China.

Xia W and Wu Z, Supplier selection with multiple criteria in volume discount environments. *Omega,* 35 (5) (2007): 494-504.

Xu J, Agile manufacturing model of small and medium-sized manufacturing enterprises, *IEEE Second International Conference on Future Information Technology and Management Engineering, 2009*.

Xu JP and Sasaki M, Technique of order preference by similarity to multiple attribute decision making based on grey members, *Transactions of IEEJ*, 124 (10) (2004): 1999-2005.

Yager RR, On ordered weighted averaging aggregation operators in multi-criteria decision making, *IEEE Transactions on Systems, Man and Cybernetics*, 18 (1988): 183–190.

Yaghoubi NM and Dahmardeh MR, Analytical approach to effective factors on organizational agility, *Journal of Basic and Applied Sciences Research*, 1 (1) (2010): 76-87.

Yaghoubi NM, Kord B and Azadikhah O, Assessing organizational agility via fuzzy logic, *International Business Research*, 4 (3) (2011): 135-144.

Yahya S and Kingsman B, Vendor rating for an entrepreneur development programme: A case study using the analytic hierarchy process method, *Journal of Operation Research Society*, 50 (9) (1999):916 - 930.

Yan H, Yu ZX and Cheng TCE, A strategic model for supply chain design with logical constraints: Formulation and solution, *Computers and Operations Research*, 30 (14) (2003): 2135-2155.

Yanfang H and Fu J, Supply Chain, The Way to Flat Organisation, pp. 404, December 2008, I-Tech, Vienna, Austria.

Yang SL and Li TF, Agility evaluation of mass customization product manufacturing, *Journal of Materials Processing Technology*, 129 (1–3) (2002): 640–644.

Yauch C, Measuring agility: combining organizational success and turbulence, *International Conference on Agile Manufacturing*, (2005).

Yauch CA, Measuring agility as a performance outcome, *Journal of Manufacturing Technology Management*, 22 (3) (2011): 384–404.

Yigin IH, Taskin H, Cedimoglu IH and Topal B, Supplier selection: An expert system approach. *Production Planning and Control*, 18 (1) (2007): 16-24.

Yoon K and Hwang C-L, Multiple Attribute Decision Making: An Introduction, Sage Publication, (1995), Thousand Oaks, California.

Yong D, Wenkang S, Feng D and Qi L, A new similarity measure of generalized fuzzy numbers and its application to pattern recognition, *Pattern Recognition Letters*, 25 (2004): 875-883.

Young SL, Technology ... The enabler for tomorrow's agile enterprise, *ISA Transactions*, 34 (4) (1995): 335-341.

Yusuf YY, Sarhadi M and Gunasekaran A, Agile manufacturing: The drivers, concepts and attributes, *International Journal of Production Economics*, 62 (1-2) (1999): 33-43.

Yusuf YY, Ren J and Burns ND, A method for evaluating enterprise agility—an empirical study, *16th International Conference on Production Research*, 29 July–3 August 2001, Prague, Czech Republic.

Yusuf YY, Gunasekaran A, Adeleye EO and Sivayoganathan K, Agile supply chain capabilities: Determinants of competitive objectives, *European Journal of Operational Research*, 159 (2) (2004): 379–392.

Yusuf YY, Gunasekaran A, Musa A, Dauda M, El-Berishy NM, Cang S, A relational study of supply chain agility, competitiveness and business performance in the oil and gas industry, *International Journal of Production Economics*, (2012) (In press): doi.org/10.1016/j.ijpe.2012.10.009.

Zadeh LA, Fuzzy Sets, *Information and Control*, 8 (3) (1965): 338-353.

Zadeh LA, The concept of a linguistic variable and its application to approximate reasoning-I and II, *Information Sciences*, 8 (3(I) 4(II)) (1975): 199–249(I); 301–357(II).

Zaeh MF, Moeller N, Vogl W, Symbiosis of changeable and virtual production–the emperor's new clothes or key factor for future success? Proceedings of the *1st International Conference on Changeable, Agile, Reconfigurable and Virtual Production*, CARV005, (2005), Munich, Germany.

Zimmermann HJ, Fuzzy Set Theory and its Applications, 2nd Ed., Kluwer Academic Publishers, (1991), Boston, Dordrecht, London.

Zakuan N, Yusof SM, Saman MZM and Shaharoun AM, Confirmatory factor analysis of TQM practices in Malaysia and Thailand automotive industries, *International Journal of Business and Management*, 5 (1) (2010): 160–175.

Zandi F and Tavana M, A fuzzy group quality function deployment model for e-CRM framework assessment in agile manufacturing, *Computers and Industrial Engineering*, 61 (1) (2011): 1–19.

Zhang J, Gu J, Li P and Duan Z, Object-oriented modeling of control system for agile manufacturing Cells, *International Journal of Production Economics*, 62 (1-2) (1999): 145-153.

Zhang JJ, Wu DS and Olson DL, The method of grey related analysis to multiple attribute decision making problems with interval numbers, *Mathematical and Computer Modeling*, 42 (9-10) (2005): 991-998.

Zhang DZ, Anosike A and Lim MK, Dynamically integrated manufacturing systems (DIMS) – a multi-agent approach', *IEEE Transactions on Systems, Man and Cybernetics*, 37 (5) (2007): 824–850.

Zhang DZ, Towards theory building in agile manufacturing strategy-A taxonomical approach, *IEEE Transactions on Engineering Management*, 54 (2) (2007): 351-370.

Zhang DZ, Towards theory building in agile manufacturing strategies-Case studies of an agility taxonomy, *International Journal of Production Economics*, (2010) (In press) doi:10.1016/j.ijpe.2010.08.010.

Zhang Z and Sharifi H, A methodology for achieving agility in manufacturing organizations, *International Journal of Operations and Production Management*, 20 (4) (2000): 496-512.

Websites:

http://rockfordconsulting.com/supply-chain-agility.htm

http://rockfordconsulting.com/mass-customization.htm

http://www.cheshirehenbury.com/agility/agilitypapers/paper0794.html

http://www.wisegeek.com/what-is-agile-manufacturing.htm

http://www.leanproduction.com/agile-manufacturing.html

http://www.ortems.com/gb-planning-scheduling/solutions/agile-manufacturing.php

http://howtoimplementleanmanufacturing.blogspot.com/2010/03/agile-manufacturing-vs-lean.html

http://www.businessknowledgesource.com/manufacturing/how_to_incorporate_agile_manufacturing_into_your_existing_system_024331.html

http://www.enjineer.com/forum/showthread.php?746-Agile-manufacturing

http://www.tmssonline.com/Agile_Manufacturing.html

http://agilemanufacturing.wordpress.com/description-of-agile-manufacturing-philosophy/

http://vmserver14.nuigalway.ie/xmlui/handle/10379/1253

http://www.businessdictionary.com/definition/agile-enterprise.html

http://www.bptg.org/bptgDisplayEvent.aspx?id=77

http://mthink.com/content/creating-agile-supply-chain

List of Publications

Journal Papers (Published)

1. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, 2012, *Interrelationship of Drivers for Agile Manufacturing: An Indian Experience*, **International Journal of Services and Operations Management (IJSOM)**, Vol. 11, No. 1, pp. 35-48, Inderscience Publishers, Switzerland.

2. **Swagatika Mishra**, Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, 2011, *Agility Extent Evaluation for Mass Customized Product Manufacturing Using Interval-Valued Fuzzy Sets (IVFS)*, **International Journal of Logistics Economics and Globalisation (IJLEG)**,Vol. 3, No. 4, pp. 210-233, Inderscience Publishers, Switzerland.

3. **Swagatika Mishra**, Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, 2012, *Multi-Attribute Group Decision Making (MAGDM) for Supplier Selection Using Fuzzy Linguistic Modeling Integrated with VIKOR Method*, **International Journal of Services and Operations Management (IJSOM)**, Vol.12, No. 1, pp. 67-89, Inderscience Publishers, Switzerland.

4. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, 2013, *Agility Evaluation and Identification of Agile Obstacles by exploring fuzzy degree of similarity (DOS) concept*, **International Journal of Information and Computation Technology**, Vol. 3, No. 1, pp. 82-86, International Research Publication House, New Delhi.

5. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, 2013, *Grey-based and Fuzzy TOPSIS decision-making approach for agility evaluation of mass customization systems*, **Benchmarking: an International Journal**, Vol. 20, No. 4, pp. 440-462, Emerald Group Publishing Limited, UK.

6. **Swagatika Mishra**, Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, 2013, *Supplier Evaluation in Agile Supply Chain in Fuzzy paradigm*, **International Journal of Services and Operations Management (IJSOM)**, Vol. 16, No. 1, pp. 1-41, Inderscience Publishers, Switzerland.

7. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, *Implementing Agility Appraisement Module in Fuzzy Context: An Indian Perspective*, 2013, **International Journal of Logistic Systems and Management (IJLSM)**, Vol. 14, No. 3, pp. 353-386, Inderscience Publishers, Switzerland.

Journal Papers (Accepted/ In Press)

1. **Swagatika Mishra**, Siba Sankar Mahapatra, Saurav Datta, *Agility Evaluation in Fuzzy Context: Influence of Decision-Makers Risk Bearing Attitude*, **Benchmarking**, **an International Journal**, Emerald Group Publishing Limited, UK. (**In Press**)

2. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, Bikash Ranjan Debata, *Alignment of Dimensions towards Modeling Organizational Supply Chain Agility*, **International Journal of Services and Operations Management (IJSOM)**, Volume 17, Number 1, pp. 88-106, Inderscience Publishers, Switzerland.

3. Chitrasen Samantra, Saurav Datta, **Swagatika Mishra**, Siba Sankar Mahapatra, *Agility Evaluation for Integrated Supply Chain Using Generalized Trapezoidal Fuzzy Numbers Set*, **International Journal of Advanced Manufacturing Technology**, Springer-Verlag London Limited. **(Available Online)** ***[http://dx.doi.org/10.1007/s00170-013-4937-6]***

4. **Swagatika Mishra**, Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, *Agility Appraisement Framework for Integrated Supply Chain Using Generalized Interval-Valued Fuzzy Set*, **International Journal of Business Information Systems (IJBIS)**, Inderscience Publishers, Switzerland. **(In Press)**

5. **Swagatika Mishra**, Anoop Kumar Sahu, Saurav Datta, and Siba Sankar Mahapatra, *Application of Fuzzy Integrated Multi-MOORA Method towards Supplier/Partner Selection in Agile Supply Chain*, **International Journal of Operational Research (IJOR)**, Inderscience Publishers, Switzerland. **(In Press)**

Paper (Under Consideration)

1. Chitrasen Samantra, Saurav Datta, **Swagatika Mishra**, Siba Sankar Mahapatra, *Fuzzy Evaluation Modeling to Assess Organizational Agility*, **Neural Computing and Applications**, Springer-Verlag London Limited. **(Under Review)**

Papers presented in conferences

1. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*Application of Grey Analysis for Vendor Selection*", **43rd Annual Convention of Operational Research Society of India (ORSI 2010) and International Conference on Operational Research on Urban and Rural Development (ORURD)**, Thiagarajar College of Engineering, Madurai-625015, December 15-17, 2010.

2. **Swagatika Mishra**, Biranchi Narayan Panda, Siba Sankar Mahapatra and Saurav Datta, "*Grey-based decision-making approach for agility evaluation of mass customization systems*", **SOM 2011, XV Annual International Conference of the Society of Operations Management on *Sustainable Operations Management***, December 17-18, 2011 at Indian Institute of Management Calcutta (IIMC), Kolkata.
3. Chitrasen Samantra, **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*Assessment and improvement of organizational agility extent using interval-valued trapezoidal fuzzy numbers set*", **National Conference on Industrial Mathematics and Soft Computing (NCIMSC-2012)** 26th -27th May, 2012, organized by Department of Mathematics, School of Applied Sciences, KIIT University, Bhubaneswar, Orissa.
4. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*Exploration of Grey Numbers towards Agility Appraisement Modeling in Supply Chain*", **National Conference on Mathematical Modeling, Simulation and Optimization (MMSO 2012)**, July 20, 2012, organized by Department of Applied Sciences, Chitkara University, Punjub.
5. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*Grey theory towards agility appraisement modeling: a case study*", **1st International Conference on Best Practices in Supply Chain Management (BPSCM-2012)**, 22nd to 23rd November 2012, Organized by the Department of Mechanical Engineering, Institute of Technical Education and Research (ITER), Siksha 'O' Anusandhan University, Bhubaneswar, Odisha.
6. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*Ranking of Agile Criterions using Fuzzy Degree of Similarity*", **International Conference on Marketing Paradigms in Emerging Economies**, organized by Faculty of Management Studies, during 4-5 December, 2012 at Banaras Hindu University (BHU), Varanasi.
7. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*Agility Evaluation and Identification of Agile Obstacles by exploring fuzzy degree of similarity (DOS) concept*", International Congress on **Innovative Trends in Information Technologies and Computing Sciences for Competitive World Order (ITITCSCWO – 2013)** organized by "Krishi Sanskriti", during 2nd-3rd March 2013 at Jawaharlal Nehru University, New Delhi-110067.
8. **Swagatika Mishra**, Anoop Kumar Sahu, Saurav Datta, Siba Sankar Mahapatra, "*Supplier Selection in Agile Supply Chain using Fuzzy based MULTIMOORA Approach*", **International Conference on Computational Intelligence and Advanced Manufacturing Research (ICCIAMR-2013)**, 5-6 April 2013, organized by Department of Mechanical Engineering, VELS University, Chennai-600117.
9. **Swagatika Mishra**, Saurav Datta, Siba Sankar Mahapatra, "*An Integrated Agility Appraisement Module in Supply Chain: A Fuzzy Based Approach*", **World Congress** on **Business, Finance, Marketing and Industrial Management for Sustainable Development, (BFMIMSD-2013)**, organized by "Krishi Sanskriti", on 25th & 26th May 2013, at Jawaharlal Nehru University, New Delhi-110067.

Resume

Name: **Swagatika Mishra**

Father's Name*:* Mr. Sukanta Mishra

Mother's Name*:* Mrs. Chandrabali Mishra

Address for Correspondence*:*

At/-House No.-E-286, GGP BDA Colony, Rasulgarh,
P: O:-Goda Gopinath Prasad, Bhubaneswar, Dist-Khurda, (Odisha)-751025

Phone No.*:* 09861289179

E-mail ID*:* swagatika.mechanical@gmail.com/ swagatika_misra@yahoo.co.in

Educational Background:

Degree	Examination Passed	Year of Passing	Institute	Board/ University	Subject/ Discipline/ Specialization
X [10]	H.S.C Exam (10th Exam)	1998	Govt. High School C.R.P, Baramunda	Board of Secondary Education, Odisha	MIL(O), Eng, Sci, Social Science, Math
XII [10+2]	H.S. Exam (+2 Science)	2000	College of Basic Science and Humanities, OUAT, Bhubaneswar	C.H.S.E., Odisha	Science (PCMB Group)
UG Degree	B.E.	2005	Krupajal Engineering College,BBSR	B.P.U.T, Odisha	Mechanical Engg.
PG Degree	M. Tech.	2009	College of Engineering and Technology, Bhubaneswar	B.P.U.T, Odisha	Industrial Engg. and Management
Doctoral	Ph. D.	2013 (Submitting Thesis)	N.IT., Rourkela (Odisha)	N.IT., Rourkela (Odisha)	Agile Manufacturing

Professional Membership*:*

Member of International Association of the Engineers (IAENG)

Skills and expertise*:*

Software: Microsoft Office package, SPSS, MATLAB, MINITAB

Expertise:

Fuzzy Logic, Regression Analysis, Operation Management, Multi-Criteria Decision Making (MCDM) Techniques

Professional Experience*:*

2009-2010

Krupajal group of institutions, Bhubaneswar
Designation: Lecturer

2007-2008

College of Engineering and Technology, Bhubaneswar
Designation: Lecturer

SWAGATIKA MISHRA

APPENDICES

CHAPTER 3: Additional Data Tables

Table 3.3: Ratings of agile criteria (Grade-III) assigned by the DMs using linguistic terms

U_i	U_{ij}	U_{ijk}	Subjective Ratings		
			DM_1	DM_2	DM_3
U_1	U_{11}	U_{111}	VG	G	G
		U_{112}	AG	G	VG
		U_{113}	G	G	VG
	U_{12}	U_{121}	MG	MG	G
		U_{122}	G	MG	G
		U_{123}	MG	MG	G
	U_{13}	U_{131}	AG	AG	G
		U_{132}	MG	AG	G
U_2	U_{21}	U_{211}	G	AG	G
		U_{212}	AG	VG	G
		U_{213}	VG	VG	G
	U_{22}	U_{221}	M	M	M
		U_{222}	G	M	G
	U_{23}	U_{23}	AG	VG	VG
U_3	U_{31}	U_{31}	AG	AG	VG
	U_{32}	U_{321}	G	MG	VG
		U_{322}	G	G	AG
		U_{323}	G	VG	G
		U_{324}	AG	VG	G
	U_{33}	U_{33}	MG	MG	M

Table 3.4: Weights of agile capabilities (Grade-I) assigned by the DMs using linguistic terms

C_i	w_i	Subjective Weights		
		DM_1	DM_2	DM_3
C_1	w_1	AH	VH	VH
C_2	w_2	MH	MH	H
C_3	w_3	VH	VH	H

Table 3.5: Weights of agile attributes (Grade-II) assigned by the DMs using linguistic terms

C_{ij}	w_{ij}	Subjective Weights		
		DM_1	DM_2	DM_3
C_{11}	w_{11}	VH	H	H
C_{12}	w_{12}	M	MH	H
C_{13}	w_{13}	AH	AH	VH
C_{21}	w_{21}	VH	VH	AH
C_{22}	w_{22}	MH	M	M
C_{23}	w_{23}	H	VH	VH
C_{31}	w_{31}	MH	MH	MH
C_{32}	w_{32}	H	H	VH
C_{33}	w_{33}	AH	VH	AH

Table 3.6: Weights of agile criteria (Grade-III) assigned by the DMs using linguistic terms

C_{ijk}	w_{ijk}	Subjective Weights		
		DM_1	DM_2	DM_3
C_{111}	w_{111}	M	MH	VH
C_{112}	w_{112}	H	H	H
C_{113}	w_{113}	VH	H	VH
C_{121}	w_{121}	VH	VH	H
C_{122}	w_{122}	MH	MH	M
C_{123}	w_{123}	VH	VH	H
C_{131}	w_{131}	MH	H	H
C_{132}	w_{132}	VH	VH	VH
C_{211}	w_{211}	H	H	H
C_{212}	w_{212}	VH	H	H
C_{213}	w_{213}	MH	MH	MH
C_{221}	w_{221}	H	VH	VH
C_{222}	w_{222}	VH	H	H
C_{23}	w_{23}	H	VH	VH
C_{31}	w_{31}	MH	MH	MH
C_{321}	w_{321}	MH	M	M
C_{322}	w_{322}	VH	VH	VH

C_{323}	w_{323}	H	H	H
C_{324}	w_{324}	H	VH	VH
C_{33}	w_{33}	AH	VH	AH

Table 3.7: Aggregated decision-making cum evaluation matrix of agile criterions (Grade III)

C_{ijk}	Fuzzy Rating U_{ijk}	Fuzzy Weight w_{ijk}
C_{111}	(0.79,0.84,0.94,0.98; 1)	(0.61,0.67,0.79,0.83; 1)
C_{112}	(0.88,0.92,0.97,0.99; 1)	(0.72,0.78,0.92,0.97; 1)
C_{113}	(0.79,0.84,0.94,0.98; 1)	(0.86,0.91,0.97,0.99; 1)
C_{121}	(0.62,0.68,0.84,0.89; 1)	(0.86,0.91,0.97,0.99; 1)
C_{122}	(0.67,0.73,0.88,0.93; 1)	(0.62,0.68,0.84,0.89; 1)
C_{123}	(0.62,0.68,0.84,0.89; 1)	(0.86,0.91,0.97,0.99; 1)
C_{131}	(0.90,0.92,0.97,0.99; 1)	(0.67,0.73,0.88,0.93; 1)
C_{132}	(0.76,0.80,0.90,0.94; 1)	(0.93,0.98,1.00,1.00; 1)
C_{211}	(0.81,0.85,0.94,0.98; 1)	(0.72,0.78,0.92,0.97; 1)
C_{212}	(0.88,0.92,0.97,0.99; 1)	(0.79,0.84,0.94,0.98; 1)
C_{213}	(0.86,0.91,0.97,0.99; 1)	(0.58,0.63,0.80,0.86; 1)
C_{221}	(0.32,0.41,0.58,0.65; 1)	(0.86,0.91,0.97,0.99; 1)
C_{222}	(0.58,0.65,0.80,0.86; 1)	(0.79,0.84,0.94,0.98; 1)
C_{23}	(0.95,0.98,1.00,1.00; 1)	(0.86,0.91,0.97,0.99; 1)
C_{31}	(0.97,0.99,1.00,1.00; 1)	(0.58,0.63,0.80,0.86; 1)
C_{321}	(0.74,0.79,0.90,0.94; 1)	(0.40,0.48,0.65,0.72; 1)
C_{322}	(0.81,0.85,0.94,0.98; 1)	(0.93,0.98,1.00,1.00; 1)
C_{323}	(0.79,0.84,0.94,0.98; 1)	(0.72,0.78,0.92,0.97; 1)
C_{324}	(0.88,0.92,0.97,0.99; 1)	(0.86,0.91,0.97,0.99; 1)
C_{33}	(0.49,0.55,0.72,0.79; 1)	(0.97,0.99,1.00,1.00; 1)

Table 3.8: Aggregated decision-making cum evaluation matrix of agile attributes (Grade II)

C_{ij}	Fuzzy Rating U_{ij}	Fuzzy Weight w_{ij}
C_{11}	(0.82,0.86,0.95,0.98; 1)	(0.79,0.84,0.94,0.98; 1)
C_{12}	(0.63,0.69,0.85,0.90; 1)	(0.54,0.60,0.76,0.82; 1)
C_{13}	(0.81,0.85,0.93,0.96; 1)	(0.97,0.99,1.00,1.00; 1)
C_{21}	(0.84,0.89,0.95,0.98; 1)	(0.95,0.98,1.00,1.00; 1)

C_{22}	(0.44,0.52,0.68,0.75; 1)	(0.40,0.48,0.65,0.72; 1)
C_{23}	(0.95,0.98,1.00,1.00; 1)	(0.86,0.91,0.97,0.99; 1)
C_{31}	(0.97,0.99,1.00,1.00; 1)	(0.58,0.63,0.80,0.86; 1)
C_{32}	(0.81,0.85,0.94,0.97; 1)	(0.79,0.84,0.94,0.98; 1)
C_{33}	(0.49,0.55,0.72,0.79; 1)	(0.97,0.99,1.00,1.00; 1)

Table 3.9: Aggregated decision-making cum evaluation matrix of agile capabilities (Grade I)

C_i	Fuzzy Rating U_i	Fuzzy Weight w_i
C_1	(0.77,0.81,0.91,0.95; 1)	(0.95,0.98,1.00,1.00; 1)
C_2	(0.80,0.85,0.90,0.92; 1)	(0.62,0.68,0.84,0.89; 1)
C_3	(0.71,0.76,0.87,0.91; 1)	(0.86,0.91,0.97,0.99; 1)

Table 3.14: Ratings of sub-criteria (Grade III) assigned by the DMs using linguistic terms

U_i	U_{ij}	U_{ijk}	Subjective Ratings			
			DM_1	DM_2	DM_3	DM_4
U_1	U_{11}	U_{111}	VG	G	G	AG
		U_{112}	AG	G	VG	VG
		U_{113}	G	G	VG	VG
	U_{12}	U_{121}	MG	MG	G	MG
		U_{122}	G	MG	G	G
		U_{123}	MG	MG	G	MG
	U_{13}	U_{131}	AG	AG	G	MG
		U_{132}	MG	AG	G	VG
U_2	U_{21}	U_{211}	G	AG	G	VG
		U_{212}	AG	VG	G	VG
		U_{213}	VG	VG	G	AG
	U_{22}	U_{221}	M	M	M	G
		U_{222}	G	M	G	M
	U_{23}	U_{23}	AG	VG	VG	AG
U_3	U_{31}	U_{31}	AG	AG	VG	G
	U_{32}	U_{321}	G	MG	VG	AG
		U_{322}	G	G	AG	G
		U_{323}	G	VG	G	G
		U_{324}	AG	VG	G	G
	U_{33}	U_{33}	MG	MG	M	M

U = Rating, corresponding to criteria C

w = Weight, corresponding to criteria C

Table 3.15: Weights of main criteria (Grade I), sub-criteria (Grade II and Grade III) assigned by the DMs using linguistic terms

C_i	w_i	Subjective Weights			
		DM_1	DM_2	DM_3	DM_4
C_1	w_1	AH	VH	VH	AH
C_2	w_2	MH	MH	H	MH
C_3	w_3	VH	VH	H	VH

Table 3.16: Weights of sub-criteria (Grade II) assigned by the DMs using linguistic terms

C_{ij}	w_{ij}	Subjective Weights			
		DM_1	DM_2	DM_3	DM_4
C_{11}	w_{11}	VH	H	H	H
C_{12}	w_{12}	M	MH	H	MH
C_{13}	w_{13}	AH	AH	VH	VH
C_{21}	w_{21}	VH	VH	AH	VH
C_{22}	w_{22}	MH	M	M	H
C_{23}	w_{23}	H	VH	VH	H
C_{31}	w_{31}	MH	MH	MH	MH
C_{32}	w_{32}	H	H	VH	H
C_{33}	w_{33}	AH	VH	AH	VH

Table 3.17: Weights of sub-sub-criteria (Grade III) assigned by the DMs using linguistic terms

C_{ijk}	w_{ijk}	Subjective Weights			
		DM_1	DM_2	DM_3	DM_4
C_{111}	w_{111}	M	MH	VH	H
C_{112}	w_{112}	H	H	H	H
C_{113}	w_{113}	VH	H	VH	VH
C_{121}	w_{121}	VH	VH	H	VH
C_{122}	w_{122}	MH	MH	M	MH
C_{123}	w_{123}	VH	VH	H	VH
C_{131}	w_{131}	MH	H	H	MH
C_{132}	w_{132}	VH	VH	VH	VH
C_{211}	w_{211}	H	H	H	H
C_{212}	w_{212}	VH	H	H	VH

C_{213}	w_{213}	MH	MH	MH	MH
C_{221}	w_{221}	H	VH	VH	VH
C_{222}	w_{222}	VH	H	H	H
C_{23}	w_{23}	H	VH	VH	H
C_{31}	w_{31}	MH	MH	MH	MH
C_{321}	w_{321}	MH	M	M	M
C_{322}	w_{322}	VH	VH	VH	H
C_{323}	w_{323}	H	H	H	H
C_{324}	w_{324}	H	VH	VH	H
C_{33}	w_{33}	AH	VH	AH	VH

Table 3.18: Aggregated fuzzy ratings and aggregated fuzzy weights of sub-criteria (Grade III)

Sub-Criteria	Fuzzy aggregated ratings, U_{ijk}	Fuzzy aggregated weights, w_{ijk}
C_{111}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1.0)]	[(0.64,0.70,0.82,0.87; 0.8), (0.64,0.70,0.82,0.87; 1.0)]
C_{112}	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1.0)]	[(0.72,0.78,0.92,0.97; 0.8), (0.72,0.78,0.92,0.97; 1.0)]
C_{113}	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1.0)]	[(0.88,0.93,0.98,0.99; 0.8), (0.88,0.93,0.98,0.99; 1.0)]
C_{121}	[(0.61,0.67,0.83,0.89; 0.8), (0.61,0.67,0.83,0.89; 1.0)]	[(0.88,0.93,0.98,0.99; 0.8), (0.88,0.93,0.98,0.99; 1.0)]
C_{122}	[(0.68,0.74,0.89,0.94; 0.8), (0.68,0.74,0.89,0.94; 1.0)]	[(0.51,0.57,0.74,0.81; 0.8), (0.51,0.57,0.74,0.81; 1.0)]
C_{123}	[(0.61,0.67,0.83,0.89; 0.8), (0.61,0.67,0.83,0.89; 1.0)]	[(0.88,0.93,0.98,0.99; 0.8), (0.88,0.93,0.98,0.99; 1.0)]
C_{131}	[(0.82,0.85,0.93,0.96; 0.8), (0.82,0.85,0.93,0.96; 1.0)]	[(0.65,0.70,0.86,0.91; 0.8), (0.65,0.70,0.86,0.91; 1.0)]
C_{132}	[(0.81,0.85,0.93,0.96; 0.8), (0.81,0.85,0.93,0.96; 1.0)]	[(0.93,0.98,1.00,1.00; 0.8), (0.93,0.98,1.00,1.00; 1.0)]
C_{211}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1.0)]	[(0.72,0.78,0.92,0.97; 0.8), (0.72,0.78,0.92,0.97; 1.0)]
C_{212}	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1.0)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1.0)]
C_{213}	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1.0)]	[(0.58,0.63,0.80,0.86; 0.8), (0.58,0.63,0.80,0.86; 1.0)]
C_{221}	[(0.42,0.50,0.66,0.73; 0.8), (0.42,0.50,0.66,0.73; 1.0)]	[(0.88,0.93,0.98,0.99; 0.8), (0.88,0.93,0.98,0.99; 1.0)]
C_{222}	[(0.52,0.59,0.75,0.81; 0.8), (0.52,0.59,0.75,0.81; 1.0)]	[(0.77,0.83,0.94,0.98; 0.8), (0.77,0.83,0.94,0.98; 1.0)]
C_{23}	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1.0)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1.0)]
C_{31}	[(0.91,0.94,0.98,0.99; 0.8), (0.91,0.94,0.98,0.99; 1.0)]	[(0.58,0.63,0.80,0.86; 0.8), (0.58,0.63,0.80,0.86; 1.0)]
C_{321}	[(0.81,0.85,0.93,0.96; 0.8), (0.81,0.85,0.93,0.96; 1.0)]	[(0.38,0.46,0.63,0.70; 0.8), (0.38,0.46,0.63,0.70; 1.0)]
C_{322}	[(0.79,0.83,0.94,0.98; 0.8), (0.79,0.83,0.94,0.98; 1.0)]	[(0.88,0.93,0.98,0.99; 0.8), (0.88,0.93,0.98,0.99; 1.0)]
C_{323}	[(0.77,0.83,0.94,0.98; 0.8), (0.77,0.83,0.94,0.98; 1.0)]	[(0.72,0.78,0.92,0.97; 0.8), (0.72,0.78,0.92,0.97; 1.0)]
C_{324}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1.0)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1.0)]
C_{33}	[(0.45,0.52,0.69,0.75; 0.8), (0.45,0.52,0.69,0.75; 1.0)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1.0)]

Table 3.19: Aggregated fuzzy ratings and aggregated fuzzy weights of sub-criteria (Grade II)

Sub-Criteria	Fuzzy aggregated ratings, U_{ij}	Fuzzy aggregated weights, w_{ij}
C_{11}	[(0.85,0.89,0.96,0.98; 0.8), (0.85,0.89,0.96,0.98; 1.0)]	[(0.77,0.83,0.94,0.98; 0.8), (0.77,0.83,0.94,0.98; 1.0)]
C_{12}	[(0.62,0.68,0.84,0.90; 0.8), (0.62,0.68,0.84,0.90; 1.0)]	[(0.55,0.61,0.77,0.83; 0.8), (0.55,0.61,0.77,0.83; 1.0)]
C_{13}	[(0.81,0.85,0.93,0.96; 0.8), (0.81,0.85,0.93,0.96; 1.0)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1.0)]
C_{21}	[(0.87,0.91,0.97,0.98; 0.8), (0.87,0.91,0.97,0.98; 1.0)]	[(0.95,0.98,1.00,1.00; 0.8), (0.95,0.98,1.00,1.00; 1.0)]
C_{22}	[(0.46,0.54,0.70,0.77; 0.8), (0.46,0.54,0.70,0.77; 1.0)]	[(0.48,0.56,0.72,0.78; 0.8), (0.48,0.56,0.72,0.78; 1.0)]
C_{23}	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1.0)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1.0)]
C_{31}	[(0.91,0.94,0.98,0.99; 0.8), (0.91,0.94,0.98,0.99; 1.0)]	[(0.58,0.63,0.80,0.86; 0.8), (0.58,0.63,0.80,0.86; 1.0)]
C_{32}	[(0.80,0.85,0.94,0.97; 0.8), (0.80,0.85,0.94,0.97; 1.0)]	[(0.77,0.83,0.94,0.98; 0.8), (0.77,0.83,0.94,0.98; 1.0)]
C_{33}	[(0.45,0.52,0.69,0.75; 0.8), (0.45,0.52,0.69,0.75; 1.0)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1.0)]

Table 3.20: Aggregated fuzzy ratings and aggregated fuzzy weights of main-criteria (Grade I)

Main Criteria	Fuzzy aggregated ratings, U_i	Fuzzy aggregated weights, w_j
C_1	[(0.78,0.82,0.91,0.95; 0.8), (0.78,0.82,0.91,0.95; 1.0)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1.0)]
C_2	[(0.81,0.85,0.91,0.95; 0.8), (0.81,0.85,0.91,0.95; 1.0)]	[(0.61,0.67,0.83,0.89; 0.8), (0.61,0.67,0.83,0.89; 1.0)]
C_3	[(0.68,0.86,0.86,0.90; 0.8), (0.68,0.86,0.86,0.90; 1.0)]	[(0.88,0.93,0.98,0.99; 0.8), (0.88,0.93,0.98,0.99; 1.0)]

Table 3.24: Ratings of sub-criteria (Grade III) assigned by the DMs using linguistic terms

C_i	C_{ij}	C_{ijk}	Subjective Ratings			
			DM_1	DM_2	DM_3	DM_4
C_1	C_{11}	C_{111}	VG	G	G	AG
		C_{112}	AG	G	VG	VG
		C_{113}	G	G	VG	VG
	C_{12}	C_{121}	MG	MG	G	MG
		C_{122}	G	MG	G	G
	C_{13}	C_{131}	AG	AG	G	MG
		C_{132}	MG	AG	G	VG
	C_{14}	C_{141}	MG	VG	G	G
		C_{142}	VG	MG	MG	G
C_2	C_{21}	C_{211}	G	AG	G	VG
		C_{212}	AG	VG	G	VG
	C_{22}	C_{221}	M	M	M	G
		C_{222}	G	M	G	M
	C_{23}	C_{231}	AG	VG	VG	AG
		C_{232}	VG	VG	G	G
		C_{233}	AG	AG	G	AG
C_3	C_{31}	C_{311}	AG	AG	VG	G
		C_{312}	AG	G	VG	G
		C_{313}	AG	VG	G	G
	C_{32}	C_{321}	G	MG	VG	AG
		C_{322}	G	G	AG	G
		C_{323}	G	VG	G	G
	C_{33}	C_{331}	MG	MG	M	M
		C_{332}	VG	AG	MG	G

Table 3.25: Weights of sub-criteria (Grade III) assigned by the DMs using linguistic terms

C_{ijk}	Subjective Weights			
	DM_1	DM_2	DM_3	DM_4
C_{111}	VH	VH	H	VH
C_{112}	H	VH	MH	H
C_{113}	M	MH	M	M
C_{121}	MH	H	M	M
C_{122}	MH	MH	H	M
C_{131}	MH	MH	MH	MH
C_{132}	AH	AH	VH	VH
C_{141}	H	H	H	H
C_{142}	MH	MH	H	MH
C_{211}	MH	M	H	MH
C_{212}	VH	VH	H	AH
C_{221}	AH	AH	AH	AH
C_{222}	MH	MH	H	MH
C_{231}	H	H	VH	H
C_{232}	AH	AH	H	AH
C_{233}	VH	H	H	VH
C_{311}	MH	M	H	H
C_{312}	H	H	H	H
C_{313}	AH	H	VH	AH
C_{321}	H	H	H	H
C_{322}	H	VH	VH	H
C_{323}	H	MH	MH	H
C_{331}	AH	VH	AH	VH
C_{332}	VH	AH	AH	VH

Table 3.26: Weights of sub-criteria (Grade II) assigned by the DMs using linguistic terms

C_{ij}	Subjective Weights			
	DM_1	DM_2	DM_3	DM_4
C_{11}	MH	MH	H	MH
C_{12}	VH	VH	H	VH
C_{13}	VH	VH	VH	H
C_{14}	MH	MH	M	MH
C_{21}	H	H	VH	H
C_{22}	VH	VH	VH	VH
C_{23}	AH	VH	AH	VH
C_{31}	H	VH	H	VH
C_{32}	VH	AH	VH	VH
C_{33}	AH	H	VH	AH

Table 3.27: Weights of main criteria (Grade I) assigned by the DMs using linguistic terms

C_{ij}	Subjective Weights			
	DM_1	DM_2	DM_3	DM_4
C_1	AH	VH	VH	AH
C_2	VH	H	VH	AH
C_3	H	VH	H	VH

Table 3.28: Average (aggregated) fuzzy ratings and average fuzzy weights of sub-criteria (Grade III)

C_{ijk}	Fuzzy aggregated ratings	Fuzzy aggregated weights
C_{111}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1)]	[(0.87,0.93,0.98,0.99; 0.8), (0.87,0.93,0.98,0.99; 1)]
C_{112}	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1)]	[(0.73,0.79,0.91,0.95; 0.8), (0.73,0.79,0.91,0.95; 1)]
C_{113}	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1)]	[(0.38,0.46,0.63,0.70; 0.8), (0.38,0.46,0.63,0.70; 1)]
C_{121}	[(0.61,0.66,0.83,0.88; 0.8), (0.61,0.66,0.83,0.88; 1)]	[(0.48,0.55,0.72,0.78; 0.8), (0.48,0.55,0.72,0.78; 1)]
C_{122}	[(0.68,0.74,0.89,0.94; 0.8), (0.68,0.74,0.89,0.94; 1)]	[(0.55,0.61,0.77,0.83; 0.8), (0.55,0.61,0.77,0.83; 1)]
C_{131}	[(0.82,0.85,0.93,0.95; 0.8), (0.82,0.85,0.93,0.95; 1)]	[(0.58,0.63,0.80,0.86; 0.8), (0.58,0.63,0.80,0.86; 1)]
C_{132}	[(0.80,0.84,0.93,0.95; 0.8), (0.80,0.84,0.93,0.95; 1)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1)]
C_{141}	[(0.73,0.79,0.91,0.95; 0.8), (0.73,0.79,0.91,0.95; 1)]	[(0.72,0.78,0.92,0.97; 0.8), (0.72,0.78,0.92,0.97; 1)]
C_{142}	[(0.70,0.75,0.88,0.92; 0.8), (0.70,0.75,0.88,0.92; 1)]	[(0.61,0.66,0.83,0.88; 0.8), (0.61,0.66,0.83,0.88; 1)]
C_{211}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1)]	[(0.55,0.61,0.77,0.83; 0.8), (0.55,0.61,0.77,0.83; 1)]
C_{212}	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1)]	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1)]
C_{221}	[(0.42,0.50,0.66,0.73; 0.8), (0.42,0.50,0.66,0.73; 1)]	[(1.00,1.00,1.00,1.00; 0.8), (1.00,1.00,1.00,1.00; 1)]
C_{222}	[(0.52,0.59,0.75,0.81; 0.8), (0.52,0.59,0.75,0.81; 1)]	[(0.61,0.66,0.83,0.88; 0.8), (0.61,0.66,0.83,0.88; 1)]
C_{231}	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1)]	[(0.77,0.83,0.94,0.97; 0.8), (0.77,0.83,0.94,0.97; 1)]
C_{232}	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1)]	[(0.93,0.94,0.98,0.99; 0.8), (0.93,0.94,0.98,0.99; 1)]
C_{233}	[(0.93,0.94,0.98,0.99; 0.8), (0.93,0.94,0.98,0.99; 1)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1)]
C_{311}	[(0.91,0.94,0.98,0.99; 0.8), (0.91,0.94,0.98,0.99; 1)]	[(0.58,0.65,0.80,0.86; 0.8), (0.58,0.65,0.80,0.86; 1)]
C_{312}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1)]	[(0.72,0.78,0.92,0.97; 0.8), (0.72,0.78,0.92,0.97; 1)]
C_{313}	[(0.84,0.88,0.96,0.98; 0.8), (0.84,0.88,0.96,0.98; 1)]	[(0.91,0.94,0.98,0.99; 0.8), (0.91,0.94,0.98,0.99; 1)]
C_{321}	[(0.81,0.85,0.93,0.96; 0.8), (0.81,0.85,0.93,0.96; 1)]	[(0.72,0.78,0.92,0.97; 0.8), (0.72,0.78,0.92,0.97; 1)]
C_{322}	[(0.79,0.84,0.94,0.97; 0.8), (0.79,0.83,0.94,0.97; 1)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1)]
C_{323}	[(0.77,0.83,0.94,0.97; 0.8), (0.77,0.83,0.94,0.97; 1)]	[(0.65,0.70,0.86,0.91; 0.8), (0.65,0.70,0.86,0.91; 1)]
C_{331}	[(0.45,0.52,0.69,0.75; 0.8), (0.45,0.52,0.69,0.75; 1)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1)]
C_{332}	[(0.81,0.85,0.93,0.96; 0.8), (0.81,0.85,0.93,0.96; 1)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1)]

Table 3.29: Average (aggregated) fuzzy ratings and average fuzzy weights of sub-criteria (Grade II)

C_{ijk}	Fuzzy aggregated ratings	Fuzzy aggregated weights
C_{11}	[(1.71,1.97,2.44,2.61; 0.8), (1.71,1.97,2.44,2.61; 1)]	[(0.61,0.66,0.83,0.88; 0.8), (0.61,0.66,0.83,0.88; 1)]
C_{12}	[(0.67,0.82,1.28,1.48; 0.8), (0.67,0.82,1.28,1.48; 1)]	[(0.87,0.93,0.98,0.99; 0.8), (0.87,0.93,0.98,0.99; 1)]
C_{13}	[(1.25,1.37,1.67,1.78; 0.8), (1.25,1.37,1.67,1.78; 1)]	[(0.87,0.93,0.98,0.99; 0.8), (0.87,0.93,0.98,0.99; 1)]
C_{14}	[(0.96,1.12,1.56,1.74; 0.8), (0.96,1.12,1.56,1.74; 1)]	[(0.51,0.57,0.74,0.80; 0.8), (0.51,0.57,0.74,0.80; 1)]
C_{21}	[(1.26,1.41,1.70,1.80; 0.8), (1.26,1.41,1.70,1.80; 1)]	[(0.77,0.83,0.94,0.97; 0.8), (0.77,0.83,0.94,0.97; 1)]
C_{22}	[(0.74,0.90,1.28,1.45; 0.8), (0.74,0.90,1.28,1.45; 1)]	[(0.93,0.98,1.00,1.00; 0.8), (0.93,0.98,1.00,1.00; 1)]
C_{23}	[(2.28,2.48,2.82,2.93; 0.8), (2.28,2.48,2.82,2.93; 1)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1)]
C_{31}	[(1.90,2.13,2.61,2.78; 0.8), (1.90,2.13,2.61,2.78; 1)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1)]
C_{32}	[(1.73,1.98,2.56,2.78; 0.8), (1.73,1.98,2.56,2.78; 1)]	[(0.94,0.98,1.00,1.00; 0.8), (0.94,0.98,1.00,1.00; 1)]
C_{33}	[(1.21,1.35,1.62,1.71; 0.8), (1.21,1.35,1.62,1.71; 1)]	[(0.91,0.94,0.98,0.99; 0.8), (0.91,0.94,0.98,0.99; 1)]

Table 3.30: Average (aggregated) fuzzy ratings and average fuzzy weights of main criteria (Grade I)

C_{ijk}	Fuzzy aggregated ratings	Fuzzy aggregated weights
C_1	[(3.24,4.00,6.09,6.95; 0.8), (3.24,4.00,6.09,6.95; 1)]	[(0.96,0.99,1.00,1.00; 0.8), (0.96,0.99,1.00,1.00; 1)]
C_2	[(3.86,4.51,5.71,6.14; 0.8), (3.86,4.51,5.71,6.14; 1)]	[(0.89,0.93,0.98,0.99; 0.8), (0.89,0.93,0.98,0.99; 1)]
C_3	[(4.31,5.09,6.66,7.22; 0.8), (4.31,5.09,6.66,7.22; 1)]	[(0.82,0.88,0.96,0.98; 0.8), (0.82,0.88,0.96,0.98; 1)]

Table 3.35: Appropriateness rating of agile criterions given by the decision-makers

3rd level indices (criterions) C_{ijk}	Linguistic rating				
	DM1	DM2	DM3	DM4	DM5
C_{111}	G	VG	G	G	G
C_{121}	MG	MG	G	MG	MG
C_{131}	M	MG	G	MG	MG
C_{141}	G	G	G	VG	VG
C_{142}	G	VG	VG	G	G
C_{211}	MG	G	G	G	MG
C_{212}	G	VG	G	VG	G
C_{221}	MG	MG	MG	MG	MG
C_{222}	M	MG	M	M	M
C_{223}	G	MG	G	MG	G
C_{224}	G	G	G	G	G
C_{231}	MP	MP	P	M	MP
C_{311}	G	G	G	G	G
C_{312}	G	VG	VG	VG	G
C_{321}	MG	M	M	M	M
C_{322}	G	G	VG	VG	G
C_{331}	M	MG	MG	MG	M
C_{332}	G	G	G	G	G
C_{411}	VG	G	VG	G	G
C_{412}	MG	G	G	G	G
C_{421}	MG	M	M	M	M
C_{422}	M	MG	M	M	M
C_{423}	G	G	G	G	G
C_{431}	MG	MG	G	G	G
C_{432}	G	M	G	G	G

Table 3.36: Priority weights of agile criterions given by the decision-makers

3rd level indices (criterions) C_{ijk}	Linguistic weight				
	DM1	DM2	DM3	DM4	DM5
C_{111}	H	H	H	H	H
C_{121}	H	VH	H	H	H
C_{131}	MH	H	MH	H	MH
C_{141}	H	H	H	H	H
C_{142}	M	H	M	H	H
C_{211}	M	MH	MH	H	H
C_{212}	VH	H	H	H	H
C_{221}	H	MH	H	MH	H
C_{222}	H	H	H	H	H
C_{223}	VH	H	H	VH	VH
C_{224}	H	H	H	H	H
C_{231}	H	VH	H	H	H
C_{311}	MH	H	MH	H	MH
C_{312}	H	H	H	VH	H
C_{321}	H	H	H	H	H
C_{322}	VH	H	H	H	VH
C_{331}	M	MH	M	M	MH
C_{332}	H	MH	H	H	H
C_{411}	VH	H	H	H	H
C_{412}	H	VH	H	H	H
C_{421}	H	H	MH	H	MH
C_{422}	H	H	H	H	H
C_{423}	H	H	H	MH	H
C_{431}	H	H	H	H	H
C_{432}	VH	H	VH	VH	H

Table 3.37: Priority weights of agile attributes given by the decision-makers

2nd level indices (attributes) C_{ij}	Linguistic Weight				
	DM1	DM2	DM3	DM4	DM5
C_{11}	H	MH	H	H	H
C_{12}	VH	H	H	H	H
C_{13}	H	VH	H	H	H
C_{14}	H	H	MH	H	MH
C_{21}	VH	H	H	H	H
C_{22}	H	MH	H	MH	H
C_{23}	H	H	H	H	H
C_{31}	VH	H	H	VH	VH
C_{32}	H	VH	H	H	H
C_{33}	H	H	H	H	MH
C_{41}	VH	H	H	H	H
C_{42}	H	H	H	MH	H
C_{43}	M	MH	H	MH	H

Table 3.38: Priority weights of agile capabilities/ enablers given by the decision-makers

1st level indices (capabilities) C_i	Linguistic weight				
	DM1	DM2	DM3	DM4	DM5
C_1	H	H	MH	H	MH
C_2	VH	H	H	H	H
C_3	H	VH	VH	H	H
C_4	H	H	VH	H	VH

Table 3.39: Aggregated grey priority weight and appropriateness rating of agile criterions

3rd level indices (criterions) C_{ijk}	w_{ijk}	Aggregated weight	U_{ijk}	Aggregated rating
C_{111}	w_{111}	[0.60, 0.90]	U_{111}	[6.60,9.20]
C_{121}	w_{121}	[0.66, 0.92]	U_{121}	[5.20,6.60]
C_{131}	w_{131}	[0.54, 0.72]	U_{131}	[5.00,6.40]
C_{141}	w_{141}	[0.60, 0.90]	U_{141}	[7.20,9.40]
C_{142}	w_{142}	[0.52, 0.74]	U_{142}	[7.80,9.60]
C_{211}	w_{211}	[0.52, 0.70]	U_{211}	[5.60,7.80]
C_{212}	w_{212}	[0.66, 0.92]	U_{212}	[7.20,9.40]
C_{221}	w_{221}	[0.56, 0.78]	U_{221}	[5.00,6.00]
C_{222}	w_{222}	[0.60, 0.90]	U_{222}	[4.20,5.20]
C_{223}	w_{223}	[0.78, 0.96]	U_{223}	[5.60,7.80]
C_{224}	w_{224}	[0.60, 0.90]	U_{224}	[6.00,9.00]
C_{231}	w_{231}	[0.66, 0.92]	U_{231}	[2.80,4.00]
C_{311}	w_{311}	[0.54, 0.72]	U_{311}	[6.00,9.00]
C_{312}	w_{312}	[0.66, 0.92]	U_{312}	[7.80,9.60]
C_{321}	w_{321}	[0.60, 0.90]	U_{321}	[4.20,5.20]
C_{322}	w_{322}	[0.72, 0.94]	U_{322}	[7.20,9.40]
C_{331}	w_{331}	[0.44, 0.54]	U_{331}	[4.60,5.60]
C_{332}	w_{332}	[0.58, 0.84]	U_{332}	[6.00,9.00]
C_{411}	w_{411}	[0.66, 0.92]	U_{411}	[7.20,9.40]
C_{412}	w_{412}	[0.66, 0.92]	U_{412}	[5.80,8.40]
C_{421}	w_{421}	[0.52, 0.74]	U_{421}	[4.20,5.20]
C_{422}	w_{422}	[0.60, 0.90]	U_{422}	[4.20,5.20]
C_{423}	w_{423}	[0.58, 0.84]	U_{423}	[6.00,9.00]
C_{431}	w_{431}	[0.60, 0.90]	U_{431}	[5.60,7.80]
C_{432}	w_{432}	[0.78, 0.96]	U_{432}	[5.60,8.20]

Table 3.40: Aggregated grey priority weight and computed appropriateness rating of agile attributes

2nd level indices (attributes) C_{ij}	w_{ij}	Aggregated weight	U_{ij}	Computed rating
C_{11}	w_{11}	[0.60, 0.90]	U_{11}	[4.40,13.80]
C_{12}	w_{12}	[0.66, 0.92]	U_{12}	[3.73,9.20]
C_{13}	w_{13}	[0.54, 0.72]	U_{13}	[3.75,8.53]
C_{14}	w_{14}	[0.56, 0.78]	U_{14}	[5.10,13.89]
C_{21}	w_{21}	[0.66, 0.92]	U_{21}	[4.73,11.95]
C_{22}	w_{22}	[0.56, 0.78]	U_{22}	[3.75,9.82]
C_{23}	w_{23}	[0.66, 0.92]	U_{23}	[2.00,5.57]
C_{31}	w_{31}	[0.78, 0.96]	U_{31}	[5.11,12.76]
C_{32}	w_{32}	[0.66, 0.92]	U_{32}	[4.18,10.23]
C_{33}	w_{33}	[0.58, 0.84]	U_{33}	[3.98,10.37]
C_{41}	w_{41}	[0.66, 0.92]	U_{41}	[4.66,12.40]
C_{42}	w_{42}	[0.58, 0.84]	U_{42}	[3.30,9.46]
C_{43}	w_{43}	[0.52, 0.70]	U_{43}	[4.15,10.79]

Table 3.41: Aggregated grey priority weight and computed appropriateness rating of agile capabilities

1st level indices (capabilities) C_i	w_i	Aggregated weight	U_i	Computed rating
C_1	w_1	[0.56, 0.78]	U_1	[3.00, 11.33]
C_2	w_2	[0.66, 0.92]	U_2	[2.50, 12.65]
C_3	w_3	[0.72, 0.94]	U_3	[3.33, 15.04]
C_4	w_4	[0.72, 0.94]	U_4	[2.90, 15.29]

Table 3.45: Assignment of criteria weight as given by evaluation team

Criteria	Subjective Weight				
	DM1	DM2	DM3	DM4	DM5
C_{111}	VH	H	H	H	VH
C_{112}	H	H	H	H	H
C_{113}	VH	VH	H	H	H
C_{114}	H	H	H	H	H
C_{115}	VH	VH	H	VH	H
C_{116}	VH	VH	H	H	VH
C_{117}	H	H	H	VH	H
C_{121}	H	H	H	H	H
C_{122}	VH	H	VH	H	H
C_{123}	VH	H	H	H	VH
C_{124}	H	H	H	H	H
C_{131}	VH	VH	H	H	H
C_{132}	H	H	H	H	H
C_{133}	VH	VH	H	VH	H
C_{134}	VH	VH	H	H	VH
C_{135}	H	H	H	VH	H
C_{211}	H	H	H	H	H
C_{212}	VH	H	VH	H	H
C_{213}	H	VH	H	H	VH
C_{214}	VH	H	H	H	VH
C_{215}	H	H	H	H	H
C_{216}	VH	VH	H	H	H
C_{217}	H	H	H	H	H
C_{218}	VH	VH	H	VH	H
C_{219}	VH	VH	H	H	VH
C_{221}	VH	H	H	H	VH
C_{222}	H	H	H	H	H
C_{223}	VH	VH	H	H	H
C_{231}	H	H	H	H	H
C_{232}	VH	VH	H	VH	H
C_{233}	VH	VH	H	H	VH
C_{311}	H	H	H	VH	H
C_{312}	H	H	H	H	H

C_{313}	VH	H	VH	H	H
C_{314}	H	VH	H	H	VH
C_{315}	VH	H	H	H	VH
C_{321}	H	H	H	H	H
C_{322}	VH	VH	H	H	H
C_{323}	H	H	H	H	H
C_{324}	VH	VH	H	VH	H
C_{325}	VH	VH	H	H	VH
C_{331}	H	H	H	VH	H
C_{332}	H	H	H	H	H
C_{333}	VH	H	H	H	VH
C_{334}	H	H	H	H	H
C_{411}	VH	VH	H	H	H
C_{412}	H	H	H	H	H
C_{413}	VH	VH	H	VH	H
C_{414}	VH	VH	H	H	VH
C_{421}	H	H	H	VH	H
C_{422}	VH	H	H	H	VH
C_{423}	H	H	H	H	H
C_{424}	VH	VH	H	H	H
C_{425}	H	H	H	H	H
C_{426}	VH	VH	H	VH	H
C_{511}	VH	VH	H	H	VH
C_{512}	H	H	H	VH	H
C_{513}	H	H	H	H	H
C_{514}	VH	H	VH	H	H
C_{515}	H	VH	H	H	VH
C_{516}	VH	H	H	VH	VH
C_{517}	H	VH	VH	VH	H
C_{518}	VH	H	H	H	VH
C_{521}	H	H	H	H	H
C_{522}	VH	VH	H	H	H

Table 3.46: Assignment of attribute weight as given by the evaluation team

Criteria	Subjective Weight				
	DM1	DM2	DM3	DM4	DM5
C_{11}	VH	H	H	H	VH
C_{12}	H	H	H	H	H
C_{13}	VH	VH	H	H	H
C_{21}	H	H	H	H	H
C_{22}	VH	VH	H	VH	H
C_{23}	VH	VH	H	H	VH
C_{31}	H	H	H	VH	H
C_{32}	H	H	H	H	H
C_{33}	VH	H	VH	H	H
C_{41}	H	VH	H	H	VH
C_{42}	VH	H	H	VH	VH
C_{51}	H	VH	VH	VH	H
C_{52}	H	H	H	H	H

Table 3.47: Assignment of priority weight corresponding to individual agile capabilities as assigned the evaluation team

Criteria	Subjective Weight				
	DM1	DM2	DM3	DM4	DM5
C_{11}	VH	VH	H	VH	H
C_{12}	H	H	H	VH	H
C_{13}	H	VH	H	H	H
C_{21}	VH	H	H	H	H
C_{22}	H	VH	VH	H	H

Table 3.48: Appropriateness rating (linguistic judgment) against agile criterions (3rd level indices) as given by the decision-makers

Criterions	Decision-Makers																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
C_{111}	H	H	H	H	H	H	H	H	H	H	H	H	H	M	VH	H	H	H	VH	H
C_{112}	H	H	H	H	H	H	H	H	H	H	H	H	H	M	H	VH	M	M	H	H
C_{113}	H	M	H	M	M	M	M	H	M	H	M	M	H	M	H	H	M	M	H	M
C_{114}	VH	M	M	M	M	M	M	VH	M	VH	M	M	VH	H	L	M	M	L	M	M
C_{115}	VH	M	VH	M	L	M	L	H	L	VH	M	L	VH	H	VH	M	M	VH	H	L
C_{116}	VH	L	H	VH	L	H	L	H	L	H	H	L	VH	VH	M	L	H	M	M	L
C_{117}	M	L	M	H	H	H	H	H	H	VH	H	H	VH	VH	L	H	M	L	L	H
C_{121}	M	VH	M	H	H	H	H	M	H	VH	H	H	H	VH	L	M	H	M	M	H
C_{122}	M	VH	M	H	M	VH	VH	M	H	VH	M	H	H	H	H	VH	H	H	M	H
C_{123}	L	H	L	M	M	VH	H	M	M	M	M	H	H	H	H	L	VH	VH	H	H
C_{124}	L	H	L	L	L	H	H	H	L	M	L	M	H	H	H	VL	H	H	H	VH
C_{131}	L	L	L	L	L	H	M	H	H	M	L	M	M	M	VH	H	H	M	M	H
C_{132}	H	L	H	L	M	H	M	VH	H	H	L	L	M	L	H	L	VH	H	M	H
C_{133}	H	M	VH	H	H	M	L	H	H	H	M	L	M	VH	H	H	H	VH	M	L
C_{134}	M	M	VH	H	H	M	L	L	VH	L	M	L	L	VH	H	M	M	M	H	L
C_{135}	L	L	H	H	VH	L	H	M	VH	L	H	H	L	H	M	M	H	H	VH	H
C_{211}	M	L	VH	VH	VH	L	H	H	H	M	H	H	L	H	H	VH	H	M	M	H
C_{212}	L	H	M	VH	H	L	H	VH	H	H	H	H	H	H	VH	H	VH	VH	L	VH
C_{213}	L	M	M	VH	H	M	H	H	H	H	VH	VH	H	H	M	H	H	L	M	VH
C_{214}	H	M	M	VH	M	M	H	VH	M	VH	VH	VH	H	M	M	M	H	M	M	VH
C_{215}	H	M	L	M	L	H	VH	H	L	VH	VH	H	H	M	L	M	H	L	M	VH
C_{216}	L	L	L	M	L	H	VH	M	L	VH	H	H	H	M	H	H	H	H	M	VH
C_{217}	L	L	L	M	M	H	VH	H	L	VH	H	H	H	L	M	VH	H	VL	M	H
C_{218}	H	H	H	H	H	M	H	H	M	H	H	H	H	L	H	H	H	H	H	H
C_{219}	H	H	H	H	H	M	M	H	M	H	H	M	M	L	H	L	VH	M	M	H
C_{221}	H	H	M	H	M	L	M	M	L	H	M	M	M	M	H	L	VH	H	M	VH
C_{222}	M	H	M	VH	M	L	L	M	L	H	M	L	L	M	M	H	H	L	H	VH
C_{223}	M	VH	L	VH	M	H	L	L	H	M	L	L	L	H	M	H	VH	M	M	VH
C_{231}	L	VH	L	VH	L	H	H	L	H	M	H	H	H	H	H	M	M	VH	VH	H
C_{232}	L	VH	VH	VH	M	H	H	H	H	M	H	H	H	VH	M	M	VH	H	H	H
C_{233}	H	VH	VH	H	M	VH	H	H	H	H	H	H	H	H	H	VH	H	M	H	VH
C_{311}	H	M	VH	M	H	VH	M	H	H	H	VH	H	VH	H	H	M	M	H	M	VH

C_{312}	H	M	H	M	H	H	M	L	M	VH	VH	M	VH	VH	M	H	H	L	H	H
C_{313}	VH	M	H	M	H	H	M	L	M	VH	VH	M	H	VH	M	H	H	H	H	H
C_{314}	VH	L	M	L	VH	H	L	H	L	VH	H	L	H	VH	H	VH	H	H	H	VH
C_{315}	M	L	M	L	VH	H	L	H	L	VH	H	L	H	VH	H	L	VH	M	VH	VH
C_{321}	M	L	L	L	VH	H	H	H	VH	VH	H	L	M	H	H	H	M	H	VH	H
C_{322}	H	H	L	M	VH	H	H	VH	VH	L	M	H	M	H	VH	M	M	L	H	VH
C_{323}	H	H	L	M	H	VH	H	H	VH	L	M	H	M	M	VH	VH	H	VH	H	VH
C_{324}	H	H	H	H	H	VH	VH	H	H	M	L	M	L	M	H	VH	H	M	M	H
C_{325}	M	L	H	H	H	VH	VH	L	H	H	L	M	L	L	H	H	VH	M	M	H
C_{331}	L	M	VH	H	M	H	H	L	H	H	H	M	M	L	M	H	H	H	H	VH
C_{332}	L	H	VH	M	M	H	VH	H	VH	H	VH	H	L	L	M	M	H	H	H	VH
C_{333}	M	VH	H	M	M	H	VH	H	VH	VH	VH	H	L	H	M	M	M	VH	H	H
C_{334}	L	H	H	L	L	H	M	M	H	VH	VH	H	H	H	M	L	VH	L	M	H
C_{411}	H	L	VH	L	L	VH	M	L	H	H	H	H	L	VH	H	VL	VH	M	M	VH
C_{412}	H	L	VH	L	L	M	L	H	M	H	H	H	L	VH	VH	H	H	VH	H	VH
C_{413}	L	H	VH	H	H	M	L	H	M	M	H	M	VH	H	H	H	H	M	H	VH
C_{414}	L	VH	H	H	VH	M	H	VH	L	L	M	L	VH	H	H	M	M	L	H	H
C_{421}	L	VH	H	H	VH	L	M	H	H	M	M	H	H	M	H	M	VH	H	M	H
C_{422}	H	VH	M	H	VH	L	L	H	VH	M	L	H	H	M	VH	L	M	M	M	L
C_{423}	H	H	M	H	VH	L	L	H	H	L	L	M	H	M	VH	VH	H	H	VH	L
C_{424}	M	H	L	VH	VH	L	VL	L	H	L	H	L	M	H	M	H	H	L	H	L
C_{425}	M	H	H	H	VH	M	M	H	H	H	H	M	H	VH	H	VH	H	M	H	H
C_{426}	H	H	H	H	H	H	H	H	H	H	H	H	M	H	H	H	H	M	VH	H
C_{511}	H	H	H	H	H	H	H	H	H	H	H	H	M	H	VH	M	VH	H	H	H
C_{512}	H	H	H	H	H	H	H	M	H	M	VH	H	H	VH	H	VH	VH	M	H	VH
C_{513}	H	VH	M	M	M	VH	M	M	H	M	VH	VH	H	VH	M	VH	H	VH	M	VH
C_{514}	M	VH	M	M	M	VH	M	H	VH	M	H	VH	H	H	M	H	H	L	M	VH
C_{515}	M	H	H	M	M	VH	VH	H	VH	L	H	VH	H	H	M	H	M	VL	L	L
C_{516}	VH	H	VH	VH	L	VH	VH	VH	VH	L	H	H	M	H	H	M	H	M	M	L
C_{517}	VH	H	VH	VH	L	H	VH	VH	VH	H	VH	H	VH	VH	VH	M	H	VH	M	L
C_{518}	H	VH	VH	VH	H	H	H	H	H	H	VH	H	VH	VH	VH	L	M	L	H	H
C_{521}	H	VH	VH	H	H	H	H	H	H	H	H	VH	H	H	H	H	VH	H	H	H
C_{522}	L	VH	VH	H	H	H	VH	VH	H	H	VH	VH	H	H	VH	M	H	M	VH	H

(Table 3.48 continued)

Criterions	Decision-Makers																			
	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
C_{111}	H	VH	H	M	H	M	VH	VH	M	H	VH	H	H	H	H	H	VH	H	H	H
C_{112}	H	H	M	M	H	H	H	H	H	M	H	VH	H	H	H	M	H	M	M	H
C_{113}	M	L	L	H	VH	M	M	L	VH	H	H	H	M	M	H	H	M	H	M	VH
C_{114}	L	M	M	M	VH	L	VL	VL	M	M	VH	M	M	M	VH	VH	L	M	H	VH
C_{115}	L	VH	H	M	H	L	VH	H	H	M	H	VH	H	H	VH	VH	H	M	VH	VH
C_{116}	M	VH	L	H	M	M	VH	M	H	M	H	M	H	H	H	H	L	M	VH	M
C_{117}	H	M	M	M	M	H	H	L	M	M	L	L	M	M	M	H	M	M	H	M
C_{121}	H	H	H	H	L	M	M	M	VH	H	M	M	H	H	M	M	VH	VH	M	L
C_{122}	H	H	M	M	L	H	L	M	VH	M	H	H	H	H	L	M	H	M	M	L
C_{123}	VH	VH	L	M	L	M	VL	M	H	H	M	VH	M	M	L	M	M	H	L	H
C_{124}	VH	H	M	M	H	H	VH	L	M	M	M	M	M	L	M	L	L	VH	M	H
C_{131}	VH	VH	H	M	M	M	H	H	H	M	H	H	M	L	H	L	H	VH	H	H
C_{132}	H	L	M	H	M	VH	VH	M	M	H	M	M	H	L	H	H	VH	H	VH	VH
C_{133}	H	H	L	VH	L	M	VH	VH	VH	H	VH	VH	H	M	VH	H	M	VH	VH	VH
C_{134}	H	M	M	H	H	H	M	H	H	H	VH	VH	H	M	H	M	M	H	H	VH
C_{135}	L	L	H	M	H	M	M	M	M	H	H	M	M	H	H	M	M	H	H	H
C_{211}	L	H	H	H	H	VH	VH	VH	VH	VH	H	H	VH	H	H	L	VH	H	L	H
C_{212}	M	H	M	M	M	VH	VH	H	VH	VH	VH	H	VH	H	VH	L	VH	VH	M	M
C_{213}	M	M	M	L	M	M	M	M	M	H	H	M	VH	H	VH	H	H	M	M	M
C_{214}	H	L	M	L	L	H	VL	L	M	H	H	M	H	VH	H	H	H	H	H	L
C_{215}	H	H	H	M	L	M	M	L	H	VH	M	M	M	VH	H	H	VH	M	H	L
C_{216}	VH	VH	L	H	H	M	VL	VL	H	VH	H	H	H	VH	H	H	M	VH	VH	H
C_{217}	VH	VH	M	M	H	H	L	L	H	VH	H	H	VH	VH	M	VH	L	H	VH	H
C_{218}	H	VH	M	H	H	M	H	M	H	VH	H	H	H	M	H	H	VH	H	H	H
C_{219}	H	H	L	M	H	H	M	VH	M	H	VH	H	VH	M	H	H	M	M	M	H
C_{221}	H	M	L	M	H	M	L	L	H	H	VH	H	H	L	M	H	M	VH	M	H
C_{222}	VH	M	M	H	H	M	M	M	H	VH	M	M	H	L	M	M	H	VH	L	M
C_{223}	VH	H	M	M	VH	H	VH	H	M	H	M	H	H	L	L	M	M	H	H	M
C_{231}	H	M	H	H	VH	M	M	VH	H	VH	M	H	VH	M	H	H	L	H	VH	M
C_{232}	H	M	M	M	H	M	L	H	H	H	M	VH	VH	H	H	VH	L	H	VH	L
C_{233}	L	L	M	M	H	H	VL	M	M	VH	H	H	VH	H	H	VH	H	VH	H	L
C_{311}	L	M	H	L	H	M	M	L	L	H	H	VH	H	H	H	H	M	H	H	H
C_{312}	M	M	M	L	M	M	L	VL	L	H	M	M	H	H	VH	H	H	H	M	H

C_{313}	M	H	L	M	M	L	L	L	M	H	L	M	M	VH	VH	M	H	M	M	VH
C_{314}	M	H	L	M	L	H	L	M	M	H	M	H	H	VH	VH	L	VH	H	L	VH
C_{315}	H	VH	M	H	L	M	H	L	VH	H	H	H	H	H	H	M	VH	H	L	VH
C_{321}	VH	M	H	H	H	L	L	VL	M	H	H	H	M	H	H	M	VH	H	M	H
C_{322}	VH	H	H	H	H	L	M	L	H	H	VH	VH	H	H	H	H	H	H	M	H
C_{323}	L	VH	M	M	H	M	L	L	VH	H	VH	VH	H	VH	H	H	H	M	M	H
C_{324}	L	H	H	H	VH	H	L	L	H	H	H	H	H	H	M	H	VH	M	H	M
C_{325}	H	M	VH	H	VH	VH	H	M	M	H	M	H	H	H	M	VH	M	H	VH	M
C_{331}	H	L	VH	M	VH	H	L	L	M	H	M	M	M	H	M	H	L	M	H	L
C_{332}	H	VH	H	M	H	M	H	L	H	M	H	M	M	M	L	VH	VH	M	H	L
C_{333}	VH	L	M	L	H	L	L	M	M	M	M	L	H	M	L	H	VH	M	M	L
C_{334}	VH	H	H	L	VH	H	L	M	VH	H	M	L	H	M	L	H	H	H	L	M
C_{411}	H	VH	M	M	H	M	L	H	H	M	M	H	M	L	M	H	M	H	H	M
C_{412}	H	M	M	M	M	L	L	L	H	H	H	M	H	L	M	VH	M	M	H	L
C_{413}	H	L	M	M	M	L	L	M	M	H	H	H	M	H	M	VH	VH	H	VH	L
C_{414}	L	H	H	H	L	VH	VL	H	VH	M	M	M	H	H	L	H	M	H	VH	H
C_{421}	L	H	H	H	L	H	L	L	VH	H	H	H	H	VH	L	H	M	H	H	H
C_{422}	M	L	L	L	H	M	M	M	M	M	M	M	H	VH	L	H	H	M	H	H
C_{423}	M	VH	L	L	VH	L	L	M	H	M	VH	H	H	H	L	H	H	H	H	H
C_{424}	M	M	M	M	H	M	VL	M	H	H	M	M	H	H	H	H	VH	M	H	H
C_{425}	VH	H	L	M	H	H	VL	VL	VH	VH	H	H	VH	H	VH	H	VH	H	VH	VH
C_{426}	H	H	M	L	H	H	L	L	H	H	H	M	M	H	H	H	VH	H	H	VH
C_{511}	H	H	H	M	H	M	M	M	VH	H	VH	M	H	H	H	H	VH	M	H	VH
C_{512}	H	H	M	H	H	L	L	L	VH	M	VH	M	H	M	H	VH	H	L	VH	H
C_{513}	VH	VH	M	H	H	VL	M	M	H	M	M	H	M	M	M	H	H	H	VH	H
C_{514}	VH	H	H	H	H	H	L	VL	H	H	L	L	H	H	M	H	M	M	VH	M
C_{515}	VH	VH	L	M	H	VH	VL	L	H	H	L	L	H	H	L	VH	L	H	H	M
C_{516}	H	H	M	H	M	M	M	VL	VH	M	H	M	M	VH	L	VH	H	H	H	H
C_{517}	H	H	VL	M	M	L	M	M	H	M	H	VH	M	VH	H	VH	VH	M	H	H
C_{518}	L	VH	H	M	VH	H	L	VL	VH	M	M	VH	H	H	H	H	VH	M	H	H
C_{521}	L	H	H	M	VH	H	VL	M	VH	H	VH	VH	H	H	H	H	M	H	H	VH
C_{522}	M	H	H	M	VH	M	L	H	VH	H	H	H	M	VH	H	H	M	M	VH	VH

(Table 3.48 continued)

Criterions	Decision-Makers																			
	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
C_{111}	H	H	H	H	H	M	M	H	H	H	H	H	H	M	H	L	H	M	H	H
C_{112}	H	H	VH	H	H	M	H	M	H	H	H	H	H	H	H	M	H	H	H	H
C_{113}	M	VH	VH	VH	M	M	VH	H	H	H	H	VH	H	H	M	VL	M	H	H	H
C_{114}	M	VH	H	VH	M	H	L	VH	VH	M	VH	VH	M	M	M	VL	M	VH	M	M
C_{115}	M	H	H	VH	L	H	H	L	VH	H	VH	H	M	H	M	L	H	M	M	M
C_{116}	H	H	VH	H	L	H	L	M	H	H	H	H	VH	VH	H	VH	VH	M	M	H
C_{117}	H	H	VH	H	H	H	H	H	H	M	H	M	VH	H	H	H	VH	H	VH	H
C_{121}	VH	VH	H	M	H	VH	M	M	VH	M	VH	M	H	H	H	M	H	M	VH	H
C_{122}	VH	VH	H	M	VH	VH	H	H	H	H	VH	H	H	H	VH	L	L	M	H	M
C_{123}	VH	H	H	L	VH	VH	VH	M	VH	VH	M	VH	H	VH	H	M	L	L	H	M
C_{124}	VH	H	VH	M	M	H	H	VH	VH	VH	M	H	H	VH	H	H	M	H	H	VH
C_{131}	H	M	H	H	M	H	M	L	M	M	H	H	M	H	VH	L	M	H	H	VH
C_{132}	H	M	H	H	L	H	L	H	M	M	H	H	VH	H	VH	VH	H	H	M	VH
C_{133}	M	L	VH	M	L	H	H	H	M	H	VH	VH	H	M	VH	H	H	VH	M	H
C_{134}	M	L	VH	M	H	M	VH	M	H	VH	VH	VH	H	M	M	L	H	VH	L	H
C_{135}	M	M	VH	L	H	M	M	L	H	VH	VH	VH	H	M	M	M	M	VH	H	H
C_{211}	H	M	H	L	VH	M	H	H	VH	H	H	H	M	H	M	H	M	M	H	M
C_{212}	H	H	H	H	H	H	VH	VH	H	H	H	H	M	M	H	VH	L	M	H	M
C_{213}	L	H	H	H	M	H	M	H	H	VH	H	H	L	H	H	L	H	M	M	L
C_{214}	L	H	VH	VH	M	VH	L	M	M	VH	VH	H	L	H	H	VL	H	H	M	L
C_{215}	L	H	VH	VH	L	VH	H	L	M	VH	VH	M	M	VH	VH	L	VH	H	H	H
C_{216}	H	H	H	H	L	VH	M	H	L	H	VH	M	H	VH	VH	M	VH	H	H	H
C_{217}	H	H	H	H	H	VH	L	M	L	H	H	M	H	H	VH	H	VH	L	H	H
C_{218}	H	H	H	H	H	H	L	H	H	H	H	H	H	H	H	VH	H	M	M	M
C_{219}	VH	H	H	H	H	H	M	VH	H	H	H	H	M	H	H	H	H	H	M	M
C_{221}	VH	VH	VH	H	M	VH	H	M	H	H	M	H	M	H	M	M	M	H	H	H
C_{222}	H	VH	H	VH	M	VH	VH	H	M	VH	M	H	M	M	M	L	M	M	H	H
C_{223}	M	VH	VH	VH	L	VH	L	M	M	VH	H	VH	H	M	L	VL	L	H	VH	M
C_{231}	L	H	H	H	L	H	H	H	M	H	H	VH	VH	L	H	L	VH	VH	H	VH
C_{232}	L	M	H	H	H	H	M	M	L	H	H	VH	VH	L	H	M	VH	VH	H	VH
C_{233}	H	M	H	H	H	H	L	VH	L	VH	VH	H	VH	H	VH	H	VH	H	M	VH
C_{311}	H	M	VH	H	VH	H	VL	H	L	H	VH	H	VH	H	M	M	H	M	M	H
C_{312}	L	L	H	H	VH	M	H	M	M	H	VH	H	H	H	M	M	H	H	L	H

C_{313}	L	L	H	M	H	M	VH	L	M	H	H	M	H	VH	H	L	M	H	H	M
C_{314}	H	L	VH	M	H	M	L	H	H	VH	H	M	H	VH	H	M	M	VH	H	M
C_{315}	H	M	VH	VH	H	L	M	VH	H	VH	H	M	M	M	L	H	L	VH	M	M
C_{321}	VH	M	VH	VH	H	L	VH	H	H	VH	H	M	M	M	L	VH	L	H	M	M
C_{322}	VH	H	H	H	M	L	H	M	H	VH	VH	M	M	M	H	H	H	H	M	H
C_{323}	VH	H	H	M	M	M	M	VH	M	H	H	L	M	M	H	L	H	H	L	VH
C_{324}	H	VH	VH	H	M	M	L	L	M	H	H	L	L	H	VH	L	H	VH	L	VH
C_{325}	H	VH	VH	H	L	M	VL	M	H	M	H	L	L	H	VH	M	H	VH	L	VH
C_{331}	H	H	H	H	L	H	M	VH	H	M	VH	M	H	VH	H	L	H	H	M	H
C_{332}	L	H	H	VH	L	H	H	H	H	M	VH	M	M	VH	H	H	VH	H	H	H
C_{333}	L	L	H	H	H	H	VH	H	VH	M	H	H	M	H	H	H	VH	M	H	H
C_{334}	H	L	VH	VH	VH	M	H	M	VH	L	H	H	M	M	M	VH	VH	M	H	H
C_{411}	M	M	VH	VH	VH	M	L	VH	VH	L	H	H	H	L	M	H	M	M	VH	VH
C_{412}	L	M	H	H	H	H	M	H	H	L	H	H	H	L	M	L	M	L	VH	VH
C_{413}	L	H	H	H	H	H	L	H	H	H	M	H	H	L	L	L	L	L	H	VH
C_{414}	H	H	H	VH	M	H	VL	M	M	H	M	VH	VH	H	L	L	L	H	H	H
C_{421}	H	VH	H	VH	M	VH	H	H	H	M	M	VH	H	H	H	M	M	M	M	H
C_{422}	H	VH	VH	H	VH	VH	VH	L	VH	M	M	VH	H	M	H	M	M	M	M	H
C_{423}	H	VH	VH	H	VH	VH	M	H	VH	H	H	VH	H	M	VH	L	L	M	L	H
C_{424}	VH	VH	VH	H	VH	H	H	M	VH	L	H	VH	H	M	VH	M	H	H	L	M
C_{425}	H	VH	H	VH	H	H	H	H	VH	H	VH	H	H	M	H	VH	VH	H	H	M
C_{426}	H	H	H	H	VH	H	L	H	H	H	VH	H	H	H	H	VH	H	H	M	H
C_{511}	H	H	H	H	VH	H	M	M	H	H	VH	H	H	H	H	H	H	H	M	H
C_{512}	VH	VH	H	VH	VH	H	H	H	H	VH	VH	H	H	VH	VH	L	H	H	L	H
C_{513}	VH	VH	VH	VH	H	VH	VH	VH	H	H	H	VH	VH	VH	VH	L	M	VH	L	H
C_{514}	H	H	VH	H	H	VH	M	H	VH	H	H	VH	VH	H	H	VL	M	VH	H	H
C_{515}	H	H	VH	H	H	VH	H	L	VH	H	H	H	VH	H	H	L	M	H	H	M
C_{516}	H	H	H	H	H	H	L	H	VH	VH	H	H	VH	H	M	VH	VH	H	H	M
C_{517}	H	VH	H	M	H	H	M	M	VH	VH	H	H	M	H	H	H	VH	VH	VH	M
C_{518}	VH	VH	VH	M	VH	M	H	H	H	VH	VH	H	M	M	H	M	H	VH	VH	L
C_{521}	VH	VH	H	L	VH	M	VH	H	H	VH	VH	VH	H	M	VH	M	H	VH	L	L
C_{522}	VH	VH	H	L	VH	M	L	M	VH	VH	VH	VH	H	M	VH	M	H	H	M	H

(Table 3.48 continued)																				
Criterions	Decision-Makers																			
	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
C_{111}	H	H	H	H	H	H	H	H	M	H	H	H	H	H	M	H	H	L	H	M
C_{112}	H	H	H	H	H	H	H	M	H	H	M	M	M	M	H	M	M	M	H	H
C_{113}	H	H	VH	H	H	H	H	H	VH	M	VH	L	H	M	H	H	VH	H	H	VH
C_{114}	H	H	H	M	M	M	H	H	H	H	H	VH	H	H	M	M	H	H	M	M
C_{115}	H	M	H	M	M	M	VH	VH	M	H	H	L	VH	H	H	M	M	VH	M	H
C_{116}	VH	M	H	M	M	M	H	VH	L	VH	M	M	H	H	VH	L	L	M	M	H
C_{117}	H	H	M	VH	H	VH	M	H	H	VH	M	H	H	VH	H	H	H	L	VH	M
C_{121}	VH	H	M	VH	H	VH	M	H	H	H	M	L	M	VH	H	H	H	H	VH	VH
C_{122}	VH	VH	M	VH	H	VH	M	H	H	H	L	VH	M	H	M	VH	VH	H	M	VH
C_{123}	H	VH	L	H	VH	L	H	M	VH	VH	L	M	H	M	M	H	H	VH	L	H
C_{124}	H	VH	L	M	VH	L	H	M	VH	VH	M	H	H	L	H	H	H	L	L	M
C_{131}	H	VH	H	H	H	H	H	M	M	H	M	VL	VH	H	H	H	M	VH	H	H
C_{132}	H	H	H	H	H	H	VH	H	M	H	H	L	VH	M	VH	H	M	L	H	M
C_{133}	H	H	H	L	M	H	VH	H	L	M	H	M	VH	H	H	VH	M	H	H	VH
C_{134}	H	H	VH	L	M	VH	H	H	H	M	VH	H	H	VH	H	VH	H	VH	M	H
C_{135}	H	M	VH	L	M	H	H	VH	H	H	VH	VH	H	H	H	VH	H	L	M	M
C_{211}	H	M	VH	L	L	M	H	VH	H	H	H	VH	H	H	H	H	H	VH	H	VH
C_{212}	VH	L	H	M	L	L	H	H	VH	M	H	M	H	M	M	H	M	M	H	VH
C_{213}	VH	L	H	M	L	H	H	H	VH	M	H	H	H	M	L	H	M	H	H	M
C_{214}	VH	L	H	M	L	H	H	VH	VH	M	VH	L	M	L	H	M	VH	H	M	M
C_{215}	VH	H	M	H	H	VH	VH	VH	M	L	VH	M	M	L	H	M	H	VH	M	H
C_{216}	VH	H	M	H	H	VH	VH	H	M	L	H	M	L	H	VH	L	H	VH	H	H
C_{217}	H	VH	L	H	VH	H	VH	H	H	VH	H	H	L	H	L	L	H	VH	H	H
C_{218}	H	H	H	H	H	H	H	H	H	H	H	H	H	H	VH	H	M	VH	H	H
C_{219}	H	H	H	H	H	H	H	M	M	H	H	L	M	M	H	H	M	H	H	M
C_{221}	VH	H	H	H	H	M	H	H	H	M	M	VL	M	M	H	M	H	M	M	H
C_{222}	VH	H	M	VH	H	M	VH	H	H	M	M	M	H	H	VH	M	H	M	M	H
C_{223}	H	VH	M	VH	VH	H	H	H	VH	M	H	VH	H	M	H	L	M	H	L	M
C_{231}	H	VH	L	H	VH	H	H	M	H	L	VH	L	H	L	M	L	M	VH	H	H
C_{232}	H	M	L	H	VH	M	VH	M	H	L	VH	H	H	L	H	H	H	VH	H	H
C_{233}	H	M	L	H	H	M	VH	M	M	H	VH	VH	VH	M	H	H	H	M	L	M
C_{311}	H	M	H	H	H	H	M	M	M	H	H	VL	H	M	H	H	VH	M	L	L
C_{312}	H	H	H	M	H	H	M	L	M	H	M	L	M	H	VH	VH	H	M	M	L

C_{313}	M	H	H	M	M	H	M	L	VH	VH	M	H	H	H	VH	H	H	L	M	M
C_{314}	M	VH	H	M	M	M	H	L	VH	VH	M	VH	M	H	H	H	M	L	M	M
C_{315}	M	VH	H	H	M	M	H	L	H	VH	H	M	H	VH	H	VH	M	H	M	VH
C_{321}	L	H	H	H	M	VH	M	L	VH	M	H	M	VH	VH	M	VH	H	M	L	M
C_{322}	L	M	VH	VH	H	H	M	H	M	M	VH	VL	H	H	L	H	VH	VH	L	H
C_{323}	L	M	VH	VH	H	H	L	H	M	M	VH	L	H	H	VH	H	VH	H	L	VH
C_{324}	M	L	VH	H	H	VH	L	H	VH	L	VH	M	H	M	H	H	VH	H	M	H
C_{325}	M	L	M	H	H	H	VH	VH	L	L	H	L	M	M	VH	VH	L	M	M	M
C_{331}	M	H	M	H	H	H	L	VH	L	H	H	VH	VH	H	H	H	L	L	VH	M
C_{332}	H	H	L	M	H	H	M	VH	L	H	M	VH	VH	H	H	H	M	L	VH	H
C_{333}	H	H	L	M	M	VH	H	H	M	H	M	M	H	H	M	VH	M	H	H	M
C_{334}	H	M	L	L	M	VH	H	H	M	M	L	L	H	H	M	VH	M	M	VH	VH
C_{411}	VH	M	H	L	L	H	VH	VH	VH	M	L	H	M	H	L	M	H	H	VH	H
C_{412}	VH	L	H	M	L	H	M	VH	H	L	H	VL	M	M	L	M	H	VH	H	H
C_{413}	VH	L	H	H	L	H	M	VH	H	L	H	M	H	M	H	L	H	VH	H	M
C_{414}	H	H	H	H	H	VH	H	H	H	H	M	VH	VH	H	VH	H	M	H	M	VH
C_{421}	H	H	H	VH	H	VH	M	H	M	H	L	L	H	H	H	L	L	H	VH	VH
C_{422}	H	M	H	H	H	H	M	H	M	H	L	VH	H	H	H	M	L	M	VH	M
C_{423}	H	M	VH	M	H	H	L	H	H	H	M	M	H	VH	H	M	L	VH	H	H
C_{424}	M	M	VH	M	H	VH	L	H	VH	H	H	H	M	VH	H	H	M	VH	H	H
C_{425}	H	VH	H	VH	H	H	M	H	H	H	H	H	M	H	VH	H	H	H	H	VH
C_{426}	M	H	H	VH	H	H	H	H	H	H	H	VL	VH	VH	H	H	H	VH	VH	H
C_{511}	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	VH	VH	VH
C_{512}	H	H	H	H	H	H	H	H	H	H	H	M	H	M	VH	VH	M	H	H	VH
C_{513}	H	H	H	H	H	VH	VH	VH	H	VH	VH	VH	M	L	VH	VH	M	VH	H	H
C_{514}	VH	H	H	VH	H	VH	VH	VH	VH	VH	VH	VL	VH	M	H	H	L	H	H	H
C_{515}	VH	H	H	VH	VH	VH	VH	H	VH	VH	VH	L	H	H	H	H	L	H	VH	H
C_{516}	H	H	H	H	VH	M	H	VH	H	H	H	M	H	H	M	M	H	M	VH	VH
C_{517}	H	VH	VH	H	VH	M	H	VH	H	H	H	VH	M	VH	M	M	H	H	H	H
C_{518}	H	VH	VH	H	H	M	H	H	H	VH	M	H	L	VH	H	L	M	H	H	VH
C_{521}	M	VH	VH	VH	H	H	VH	H	H	VH	M	L	L	H	H	L	L	H	VH	VH
C_{522}	M	M	M	VH	H	M	VH	H	H	H	H	H	VH	H	M	VH	L	H	VH	VH

Table 3.49: Aggregated weight and appropriateness rating of agile criterions

3rd level indices (criterions) C_{ijk}	w_{ijk}	Aggregated weight	U_{ijk}	Aggregated rating
C_{111}	W_{111}	(1,0.85,1)	U_{111}	(0.48,0.73,0.95)
C_{112}	W_{112}	(1,0.75,1)	U_{112}	(0.45,0.70,0.94)
C_{113}	W_{113}	(1,0.85,1)	U_{113}	(0.43,0.68,0.88)
C_{114}	W_{114}	(1,0.75,1)	U_{114}	(0.38,0.62,0.82)
C_{115}	W_{115}	(1,0.9,1)	U_{115}	(0.42,0.67,0.86)
C_{116}	W_{116}	(1,0.9,1)	U_{116}	(0.39,0.64,0.84)
C_{117}	W_{117}	(1,0.8,1)	U_{117}	(0.42,0.67,0.88)
C_{121}	W_{121}	(1,0.75,1)	U_{121}	(0.45,0.7,0.90)
C_{122}	W_{122}	(1,0.85,1)	U_{122}	(0.45,0.70,0.89)
C_{123}	W_{123}	(1,0.85,1)	U_{123}	(0.4,0.64,0.83)
C_{124}	W_{124}	(1,0.75 ,1)	U_{124}	(0.39,0.63,0.84)
C_{131}	W_{131}	(1,0.85 ,1)	U_{131}	(0.39,0.63,0.86)
C_{132}	W_{132}	(1,0.75 ,1)	U_{132}	(0.41,0.66,0.87)
C_{133}	W_{133}	(1,0.90,1)	U_{133}	(0.46,0.71,0.89)
C_{134}	W_{134}	(1,0.90,1)	U_{134}	(0.43,0.68,0.87)
C_{135}	W_{135}	(1,0.80 ,1)	U_{135}	(0.40,0.65,0.86)
C_{211}	W_{211}	(1,0.75 ,1)	U_{211}	(0.46,0.71,0.90)
C_{212}	W_{212}	(1,0.85 ,1)	U_{212}	(0.46,0.71,0.89)
C_{213}	W_{213}	(1,0.85 ,1)	U_{213}	(0.38,0.63,0.86)
C_{214}	W_{214}	(1,0.85,1)	U_{214}	(0.39,0.63,0.83)
C_{215}	W_{215}	(1,0.75 ,1)	U_{215}	(0.41,0.66,0.85)
C_{216}	W_{216}	(1,0.85 ,1)	U_{216}	(0.44,0.68,0.88)
C_{217}	W_{217}	(1,0.75,1)	U_{217}	(0.43,0.68,0.87)
C_{218}	W_{218}	(1,0.90,1)	U_{218}	0.48,0.73,0.96)
C_{219}	W_{219}	(1,0.90,1)	U_{219}	(0.42,0.67,0.9)
C_{221}	W_{221}	(1,0.85,1)	U_{221}	(0.38,0.63,0.85)
C_{222}	W_{222}	(1,0.75,1)	U_{222}	(0.38,0.63,0.84)
C_{223}	W_{223}	(1,0.85,1)	U_{223}	(0.39,0.64,0.83)
C_{231}	W_{231}	(1,0.75,1)	U_{231}	(0.43,0.68,0.87)
C_{232}	W_{232}	(1,0.90,1)	U_{232}	(0.44,0.69,0.89)
C_{233}	W_{233}	(1,0.90,1)	U_{233}	(0.47,0.71,0.90)
C_{311}	W_{311}	(1,0.80,1)	U_{311}	(0.41,0.66,0.87)
C_{312}	W_{312}	(1,0.75,1)	U_{312}	(0.37,0.62,0.84)

C_{313}	W_{313}	(1,0.85,1)	U_{313}	(0.38,0.63,0.84)
C_{314}	W_{314}	(1,0.85,1)	U_{314}	(0.40,0.65,0.85)
C_{315}	W_{315}	(1,0.85,1)	U_{315}	(0.42,0.67,0.86)
C_{321}	W_{321}	(1,0.75 ,1)	U_{321}	(0.41,0.65,0.85)
C_{322}	W_{322}	(1,0.85,1)	U_{322}	(0.43,0.68,0.88)
C_{323}	W_{323}	(1,0.75,1)	U_{323}	(0.43,0.68,0.87)
C_{324}	W_{324}	(1,0.90,1)	U_{324}	(0.41,0.66,0.87)
C_{325}	W_{325}	(1,0.90,1)	U_{325}	(0.39,0.64,0.83)
C_{331}	W_{331}	(1,0.80,1)	U_{331}	(0.39,0.64,0.85)
C_{332}	W_{332}	(1,0.75,1)	U_{332}	(0.43,0.68,0.88)
C_{333}	W_{333}	(1,0.85 ,1)	U_{333}	(0.39,0.64,0.85)
C_{334}	W_{334}	(1,0.75,1)	U_{334}	(0.38,0.63,0.83)
C_{411}	W_{411}	(1,0.85,1)	U_{411}	(0.39,0.64,0.83)
C_{412}	W_{412}	(1,0.75,1)	U_{412}	(0.35,0.6,0.81)
C_{413}	W_{413}	(1,0.90,1)	U_{413}	(0.37,0.62,0.84)
C_{414}	W_{414}	(1,0.90,1)	U_{414}	(0.42,0.66,0.87)
C_{421}	W_{421}	(1,0.80,1)	U_{421}	(0.42,0.67,0.88)
C_{422}	W_{422}	(1,0.85,1)	U_{422}	(0.38,0.63,0.84)
C_{423}	W_{423}	(1,0.75 ,1)	U_{423}	(0.42,0.67,0.86)
C_{424}	W_{424}	(1,0.85 ,1)	U_{424}	(0.41,0.65,0.85)
C_{425}	W_{425}	(1,0.75,1)	U_{425}	(0.52,0.76,0.94)
C_{426}	W_{426}	(1,0.90 ,1)	U_{426}	(0.48,0.73,0.94)
C_{511}	W_{511}	(1,0.90,1)	U_{511}	(0.50,0.75,0.97)
C_{512}	W_{512}	(1,0.80,1)	U_{512}	(0.49,0.74,0.93)
C_{513}	W_{513}	(1,0.75,1)	U_{513}	(0.52,0.76,0.91)
C_{514}	W_{514}	(1,0.85,1)	U_{514}	(0.47,0.71,0.89)
C_{515}	W_{515}	(1,0.85,1)	U_{515}	(0.44,0.69,0.87)
C_{516}	W_{516}	(1,0.90,1)	U_{516}	(0.47,0.71,0.90)
C_{517}	W_{517}	(1,0.90,1	U_{517}	(0.50,0.75,0.92)
C_{518}	W_{518}	(1,0.85,1)	U_{518}	(0.49,0.73,0.91)
C_{521}	W_{521}	(1,0.75,1)	U_{521}	(0.50,0.74,0.92)
C_{522}	W_{522}	(1,0.85,1)	U_{522}	(0.50,0.75,0.91)

Table 3.50: Aggregated weight and computed appropriateness rating of agile attributes

2nd level indices (attributes) C_{ij}	w_{ij}	Aggregated weight	U_{ij}	Computed rating
C_{11}	W_{11}	(0.60,0.85,1)	U_{11}	(0.25, 0.67, 1.53)
C_{12}	W_{12}	(0.50,0.75,1)	U_{12}	(0.23, 0.67, 1.57)
C_{13}	W_{13}	(0.60,0.85,1)	U_{13}	(0.25, 0.67, 1.47)
C_{21}	W_{21}	(0.50,0.75,1)	U_{21}	(0.25, 0.68, 1.52)
C_{22}	W_{22}	(0.65,0.90,1)	U_{22}	(0.22, 0.64, 1.49)
C_{23}	W_{23}	(0.65,0.90,1)	U_{23}	(0.27, 0.7, 1.48)
C_{31}	W_{31}	(0.55,0.80,1)	U_{31}	(0.23, 0.65, 1.49)
C_{32}	W_{32}	(0.50,0.75,1)	U_{32}	(0.24, 0.66, 1.48)
C_{33}	W_{33}	(0.60,0.85,1)	U_{33}	(0.21, 0.65, 1.59)
C_{41}	W_{41}	(0.60,0.85,1)	U_{41}	(0.23, 0.63, 1.40)
C_{42}	W_{42}	(0.65,0.90,1)	U_{42}	(0.25, 0.68, 1.57)
C_{51}	W_{51}	(0.65,0.90,1)	U_{51}	(0.29, 0.73, 1.52)
C_{52}	W_{52}	(0.50,0.75,1)	U_{52}	(0.27, 0.75, 1.66)

Table 3.51: Aggregated weight and computed appropriateness rating of agile capabilities

1st level indices (capabilities) C_i	w_i	Aggregated weight	U_i	Computed rating
C_1	W_1	(0.65, 0.9,1)	U_1	(0.14, 0.67, 2.69)
C_2	W_2	(0.55, 0.8,1)	U_2	(0.15, 0.67, 2.49)
C_3	W_3	(0.55, 0.8,1)	U_3	(0.12, 0.65, 2.77)
C_4	W_4	(0.55, 0.8,1)	U_4	(0.15, 0.66, 2.37)
C_5	W_5	(0.6, 0.85,1)	U_5	(0.16, 0.74, 2.77)

Table 3.53: Appropriateness rating (linguistic judgment) against agile 2nd level attributes as given by the decision-makers (DMs)

2nd level attributes	Appropriateness rating (linguistic judgment) against agile 2nd level attributes as given by the decision-makers (DMs)																			
	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10	DM11	DM12	DM13	DM14	DM15	DM16	DM17	DM18	DM19	DM20
C_{11}	M	L	L	VL	L	VL	M	L	L	VL	M	L	M	VL	M	M	L	VL	VL	VL
C_{12}	M	L	L	VL	L	VL	M	L	L	VL	M	H	M	VL	M	M	VL	VL	M	H
C_{13}	M	H	M	M	M	L	M	H	H	VL	M	VH	M	M	M	M	H	L	H	VH
C_{21}	M	M	M	M	L	VL	M	M	M	L	M	M	L	M	L	M	H	L	H	M
C_{22}	H	H	M	H	M	M	M	H	M	L	M	H	L	H	H	M	M	L	M	M
C_{23}	H	H	VH	H	M	L	H	H	H	L	H	VH	M	H	H	M	H	M	VH	VH
C_{31}	H	H	H	M	L	L	M	H	M	M	VH	VH	L	M	M	M	H	M	H	VH
C_{32}	H	VH	VH	VH	M	M	M	VH	H	H	VH	VH	M	VH	VH	H	H	H	H	VH
C_{33}	H	H	H	H	M	L	H	H	H	H	H	H	L	H	H	H	H	M	M	H
C_{41}	H	M	VH	H	L	L	M	H	M	M	H	M	L	H	H	M	H	L	H	M
C_{42}	L	L	L	L	L	L	L	M	L	M	H	M	L	M	L	M	L	L	M	M
C_{51}	M	M	L	H	L	M	M	L	L	M	H	H	M	M	M	M	H	L	M	M
C_{52}	M	M	L	L	L	M	M	L	L	M	H	H	M	L	M	M	L	L	M	M

Table 3.54: Aggregated fuzzy weight and appropriateness rating against each 2nd level agile attributes

2nd level indices (attributes) C_{ij}	w_{ij}	Aggregated fuzzy weight	U_{ij}	Aggregated fuzzy rating
C_{11}	w_{11}	(0.60,0.85,1)	U_{11}	(0.0750,0.2375,0.4875)
C_{12}	w_{12}	(0.50,0.75,1)	U_{12}	(0.1375,0.3125,0.5625)
C_{13}	w_{13}	(0.60,0.85,1)	U_{13}	(0.3250,0.5625,0.7875)
C_{21}	w21	(0.50,0.75,1)	U_{21}	(0.2000,0.4375,0.6875)
C_{22}	w_{22}	(0.65,0.90,1)	U_{22}	(0.3000,0.5500,0.8000)
C_{23}	w_{23}	(0.65,0.90,1)	U_{23}	(0.4500,0.7000,0.9000)
C_{31}	w_{31}	(0.55,0.80,1)	U_{31}	(0.3625,0.6125, 0.8250)
C_{32}	w_{32}	(0.50,0.75,1)	U_{32}	(0.5625,0.8125, 0.9500)
C_{33}	w_{33}	(0.60,0.85,1)	U_{33}	(0.4125,0.6625, 0.9125)
C_{41}	w_{41}	(0.60,0.85,1)	U_{41}	(0.3250,0.5750,0.8125)
C_{42}	w_{42}	(0.65,0.90,1)	U_{42}	(0.1125,0.3625, 0.6125)
C_{51}	w_{51}	(0.65,0.90,1)	U_{51}	(0.2375,0.4875, 0.7375)
C_{52}	w_{52}	(0.50,0.75,1)	U_{52}	(0.1750,0.4250,0.6750)

Table 3.55: Aggregated fuzzy weight and computed appropriateness rating against each 1st level agile capabilities

1st level agile capabilities, C_i	w_i	Aggregated fuzzy weight	U_i	Computed fuzzy rating
C_1	w_1	(0.65, 0.9,1)	U_1	(0.1029,0.3732,1.0809)
C_2	w_2	(0.55, 0.8,1)	U_2	(0.1958,0.5699, 1.3264)
C_3	w_3	(0.55, 0.8,1)	U_3	(0.2427,0.6927,1.6288)
C_4	w_4	(0.55, 0.8,1)	U_4	(0.1341,0.4657,1.14)
C_5	w_5	(0.6, 0.85,1)	U_5	(0.1209,0.4591,1.2283)

CHAPTER 4: Additional Data Tables

Table 4.3: Weights of agile providers (Grade II) assigned by the DMs using linguistic terms

C_i	w_i	Subjective Weights			
		DM_1	DM_2	DM_3	DM_4
C_1	w_1	AH	VH	VH	H
C_2	w_2	MH	MH	H	VH
C_3	w_3	VH	VH	H	AH
C_4	w_4	AH	H	AH	H
C_5	w_5	VH	H	H	H
C_6	w_6	VH	AH	VH	VH

Table 4.4: Weights of agile attributes (Grade III) assigned by the DMs using linguistic terms

C_{ij}	w_{ij}	Subjective Weights			
		DM_1	DM_2	DM_3	DM_4
C_{11}	w_{11}	VH	H	H	H
C_{12}	w_{12}	M	MH	H	VH
C_{21}	w_{21}	AH	AH	VH	AH
C_{22}	w_{22}	VH	VH	AH	AH
C_{23}	w_{23}	MH	M	M	H
C_{24}	w_{24}	H	VH	VH	H
C_{31}	w_{31}	MH	MH	MH	VH
C_{32}	w_{32}	H	H	VH	VH
C_{41}	w_{41}	AH	VH	AH	VH
C_{42}	w_{42}	H	H	H	VH
C_{51}	w_{51}	AH	H	H	AH
C_{52}	w_{52}	H	H	VH	VH
C_{61}	w_{61}	VH	VH	VH	H
C_{62}	w_{62}	AH	AH	H	VH
C_{63}	w_{63}	H	VH	VH	H

Table 4.5: Ratings of agile attributes (Grade III) assigned by the DMs using linguistic terms

U_i	U_{ij}	Subjective Ratings			
		DM_1	DM_2	DM_3	DM_4
U_1	U_{11}	VG	G	G	MP
	U_{12}	MG	MG	G	M
U_2	U_{21}	G	AG	G	M
	U_{22}	M	M	M	G
	U_{23}	AG	VG	VG	VG
	U_{24}	MG	AG	G	MG
U_3	U_{31}	AG	AG	VG	G
	U_{32}	G	MG	VG	G
U_4	U_{41}	G	G	AG	M
	U_{42}	G	VG	G	MP
U_5	U_{51}	AG	VG	G	G
	U_{52}	MG	MG	M	G
U_6	U_{61}	AG	G	VG	VG
	U_{62}	G	G	VG	M
	U_{63}	G	MG	G	MG

Table 4.6: Aggregated fuzzy rating and priority weights for agile attributes (Grade III)

C_{ij}	U_{ij}	w_{ij}
C_{11}	(0.63,0.69,0.80,0.84; 0.8)	(0.77,0.83,0.94,0.98; 0.8)
C_{12}	(0.55,0.61,0.77,0.83; 0.8)	(0.64,0.70,0.82,0.87; 0.8)
C_{21}	(0.69,0.74,0.85,0.89; 0.8)	(0.98,0.99,1.00,1.00; 0.8)
C_{22}	(0.42,0.50,0.66,0.73; 0.8)	(0.96,0.99,1.00,1.00; 0.8)
C_{23}	(0.95,0.98,1.00,1.00; 0.8)	(0.48,0.56,0.72,0.78; 0.8)
C_{24}	(0.72,0.76,0.88,0.92; 0.8)	(0.82,0.88,0.96,0.98; 0.8)
C_{31}	(0.91,0.94,0.98,0.99; 0.8)	(0.67,0.72,0.85,0.89; 0.8)
C_{32}	(0.74,0.79,0.91,0.95; 0.8)	(0.82,0.88,0.96,0.98; 0.8)
C_{41}	(0.69,0.74,0.85,0.89; 0.8)	(0.96,0.99,1.00,1.00; 0.8)
C_{42}	(0.63,0.69,0.80,0.84; 0.8)	(0.77,0.83,0.94,0.98; 0.8)
C_{51}	(0.84,0.88,0.96,0.98; 0.8)	(0.86,0.89,0.96,0.98; 0.8)
C_{52}	(0.55,0.61,0.77,0.83; 0.8)	(0.82,0.88,0.96,0.98; 0.8)
C_{61}	(0.89,0.93,0.98,0.99; 0.8)	(0.88,0.93,0.98,0.99; 0.8)
C_{62}	(0.67,0.74,0.85,0.90; 0.8)	(0.91,0.94,0.98,0.99; 0.8)
C_{63}	(0.65,0.70,0.86,0.91; 0.8)	(0.82,0.88,0.96,0.98; 0.8)

Table 4.7: Computed fuzzy rating and aggregated fuzzy priority weights for agile providers (Grade II)

C_i	U_i	w_i
C_1	(0.59,0.65,0.78,0.83; 0.8)	(0.89,0.93,0.98,0.99; 0.8)
C_2	(0.65,0.71,0.83,0.87; 0.8)	(0.70,0.75,0.88,0.92; 0.8)
C_3	(0.81,0.86,0.94,0.96; 0.8)	(0.89,0.93,0.98,0.99; 0.8)
C_4	(0.66,0.72,0.82,0.81; 0.8)	(0.86,0.89,0.96,0.98; 0.8)
C_5	(0.70,0.74,0.86,0.90; 0.8)	(0.77,0.83,0.94,0.98; 0.8)
C_6	(0.74,0.79,0.89,0.93; 0.8)	(0.95,0.98,1.00,1.00; 0.8)

Case Study 1

Table 4.29: Membership functions for linguistic rating set S (β=0.5)

Linguistic Values	Fuzzy numbers
Very Good (VG)	(7,8.5,10)
Good (G)	(5,7.5,10)
Fair (F)	(3,5,7)
Poor (P)	(0,2.5,5)
Very Poor (VP)	(0,1.5,3)

Table 4.30: Membership functions for linguistic weighting set W (β=0.5)

Linguistic Values	Fuzzy numbers
Very High (VH)	(0.7,0.85,1)
High (H)	(0.5,0.75,1)
Medium (M)	(0.3,0.5,0.7)
Low (L)	(0,0.25,0.5)
Very Low (VL)	(0,0.15,0.3)

Table 4.31: Criteria ratings assigned by experts (Level 3 indices)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4
1.	I_1	I_{11}	I_{111}	P	VG	VP	P
			I_{112}	P	F	P	F
			I_{113}	F	P	F	F
			I_{114}	F	VP	P	P
			I_{115}	G	VG	VG	G
			I_{116}	F	P	VG	F
			I_{117}	G	VG	G	G
		I_{12}	I_{121}	VG	VG	G	VG
			I_{122}	F	G	G	G
			I_{123}	G	P	F	F
			I_{124}	G	F	G	G
		I_{13}	I_{131}	P	VG	G	F
			I_{132}	G	VG	VG	G
			I_{133}	P	VP	F	P
			I_{134}	G	F	G	F
			I_{135}	G	F	F	P
2.	I_2	I_{21}	I_{211}	VP	G	G	F
			I_{212}	VP	F	P	VP
			I_{213}	P	P	F	F
			I_{214}	P	P	VG	VP
			I_{215}	F	VP	G	F
			I_{216}	P	G	F	G
			I_{217}	G	F	VG	F
			I_{218}	F	F	G	F
			I_{219}	VP	VP	P	P
		I_{22}	I_{221}	G	VG	VG	VG
			I_{222}	G	F	G	F
			I_{223}	P	G	F	F
		I_{23}	I_{231}	F	G	G	P
			I_{232}	P	VP	P	F
			I_{233}	F	G	G	P
3.	I_3	I_{31}	I_{311}	F	G	G	F
			I_{312}	P	F	P	F

			I_{313}	G	G	F	P
			I_{314}	G	F	G	F
			I_{315}	VG	G	G	VG
		I_{32}	I_{321}	G	P	VP	F
			I_{322}	P	F	F	P
			I_{323}	G	G	G	F
			I_{324}	G	G	F	G
			I_{325}	G	VG	G	F
		I_{33}	I_{331}	G	G	VG	VG
			I_{332}	P	VP	P	VP
			I_{333}	VP	P	VP	VP
			I_{334}	F	P	F	F
4.	I_4	I_{41}	I_{411}	G	F	F	F
			I_{412}	G	F	G	F
			I_{413}	VG	VG	VG	G
			I_{414}	G	G	G	VG
		I_{42}	I_{421}	F	G	F	G
			I_{422}	P	F	P	F
			I_{423}	G	G	G	G
			I_{424}	VG	G	VG	VG
			I_{425}	G	VG	G	G
			I_{426}	G	VG	VG	VG
5.	I_5	I_{51}	I_{511}	G	VG	G	VG
			I_{512}	F	G	VG	VG
			I_{513}	P	F	F	P
			I_{514}	F	VG	G	G
			I_{515}	F	F	F	F
			I_{516}	G	G	G	VG
			I_{517}	VG	VG	VG	F
			I_{518}	G	G	G	VG
		I_{52}	I_{521}	G	VG	G	VG
			I_{522}	VG	G	G	VG

Table 4.32: Criteria weights as suggested by experts (for Level 3 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W_{ij})
1.	I_1	I_{11}	I_{111}	M	M	H	M	[.3500,.5625,.7750]
			I_{112}	VH	M	M	M	[.4000,.5875,.7750]
			I_{113}	H	VH	H	H	[.5500,.7750,1.0000]
			I_{114}	H	M	M	VH	[.4500,.6500,.8500]
			I_{115}	M	H	VH	M	[.4500,.6500,.8500]
			I_{116}	M	M	H	M	[.3500,.5625,.7750]
			I_{117}	H	H	VH	VH	[.6000,.8000,1.0000]
		I_{12}	I_{121}	H	VH	H	VH	[.6000,.8000,1.0000]
			I_{122}	M	VH	M	H	[.4500,.6500,.8500]
			I_{123}	M	M	H	VH	[.4500,.6500,.8500]
			I_{124}	H	VH	VH	H	[.6000,.8000,1.0000]
		I_{13}	I_{131}	H	H	VH	H	[.5500,.7750,1.0000]
			I_{132}	M	M	H	VH	[.4500,.6500,.8500]
			I_{133}	M	M	H	M	[.3500,.5625,.7750]
			I_{134}	VH	H	VH	H	[.6000,.8000,1.0000]
			I_{135}	M	M	H	H	[.4000,.6250,.8500]
2.	I_2	I_{21}	I_{211}	M	H	VH	H	[.5000,.7125,.9250]
			I_{212}	H	M	M	H	[.4000,.6250,.8500]
			I_{213}	VH	H	VH	M	[.5500,.7375,.9250]
			I_{214}	M	M	H	H	[.4000,.6250,.8500]
			I_{215}	H	M	VH	VH	[.5500,.7375,.9250]
			I_{216}	VH	VH	H	H	[.6000,.8000,1.0000]
			I_{217}	H	H	H	M	[.4500,.6875,.9250]
			I_{218}	M	H	VH	H	[.5000,.7125,..9250]
			I_{219}	H	VH	H	VH	[.6000,.8000,1.0000]
		I_{22}	I_{221}	M	H	VH	VH	[.5500,.7375,.9250]
			I_{222}	H	VH	H	H	[0.5500,0.7750,1.0000]
			I_{223}	H	H	M	H	[.4500,.6875,.9250]
		I_{23}	I_{231}	M	H	H	H	[.4500,.6875,.9250]
			I_{232}	H	M	H	M	[.4000,.6250,.8500]
			I_{233}	H	H	VH	H	[0.5500,0.7750,1.0000]
3.	I_3	I_{31}	I_{311}	H	M	H	M	[.4000,.6250,.8500]
			I_{312}	H	M	H	M	[.4000,.6250,.8500]
			I_{313}	M	H	VH	H	[0.5000,0.7125,0.9250]

			I_{314}	M	M	H	VH	[.4500,.6500,.8500]
			I_{315}	H	VH	H	H	[2.1250,2.6875,3.2500]
		I_{32}	I_{321}	M	H	H	H	[.4500,.6875,.9250]
			I_{322}	M	M	VH	H	[.4500,.6500,.8500]
			I_{323}	H	H	VH	VH	[.6000,.8000,1.0000]
			I_{324}	M	H	H	H	[.4500,.6875,.9250]
			I_{325}	H	M	H	H	[.4500,.6875,.9250]
		I_{33}	I_{331}	M	H	H	VH	[.5000,.7125,.9250]
			I_{332}	M	VH	VH	M	[.5000,.6750,.8500]
			I_{333}	H	H	M	H	[.4500,.6875,.9250]
			I_{334}	H	H	H	M	[.4500,.6875,.9250]
4.	I_4	I_{41}	I_{411}	M	H	H	H	[.4500,.6875,.9250]
			I_{412}	M	H	VH	H	[.5000,.7125,.9250]
			I_{413}	H	VH	H	VH	[.6000,.8000,1.0000]
			I_{414}	H	H	VH	H	[.5500,.7750,1.0000]
		I_{42}	I_{421}	H	M	H	H	[.4500,.6875,.9250]
			I_{422}	M	H	H	VH	[.5000,.7125,.9250]
			I_{423}	H	M	VH	VH	[.5500,.7375,.9250]
			I_{424}	VH	H	H	H	[.5500,.7750,1.0000]
			I_{425}	H	H	VH	H	[.5500,.7750,.1.0000]
			I_{426}	H	M	H	H	[.4500,.6875,.9250]
5.	I_5	I_{51}	I_{511}	H	H	H	H	[.5000,.7500,1.0000]
			I_{512}	VH	H	VH	H	[.6000,.8000,1.0000]
			I_{513}	H	VH	H	M	[.5000,.7125,.9250]
			I_{514}	VH	H	VH	VH	[.6500,.8250,1.0000]
			I_{515}	M	H	H	H	[.4500,.6875,.9250]
			I_{516}	H	VH	H	VH	[.6000,.8000,1.0000]
			I_{517}	VH	H	VH	H	[.6000,.8000,1.0000]
			I_{518}	VH	H	H	H	[.5500,.7750,1.0000]
		I_{52}	I_{521}	H	M	H	VH	[.4500,.6875,.9250]
			I_{522}	H	VH	H	VH	[.6000,.8000,1.0000]

Table 4.33: Attribute weights suggested by experts (for Level 2 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W_i)
1.	I_1	I_{11}	I_{111} I_{112} I_{113} I_{114} I_{115} I_{116} I_{117}	H	VH	H	VH	[0.6000,0.8000,1.0000]
		I_{12}	I_{121} I_{122} I_{123} I_{124}	VH	H	VH	VH	[0.6500, 0.8250 ,1.0000]
		I_{13}	I_{131} I_{132} I_{133} I_{134} I_{135}	M	M	H	H	[0.4000,0.6250,0.8500]
2.	I_2	I_{21}	I_{211} I_{212} I_{213} I_{214} I_{215} I_{216} I_{217} I_{218} I_{219}	H	H	H	VH	[0.5500,0.7750,1.0000]
		I_{22}	I_{221} I_{222} I_{223}	VH	VH	H	H	[0.6000, 0.8000,1.0000]
		I_{23}	I_{231} I_{232} I_{233}	M	M	H	M	[0.3500,0.5625,0.7750]
3.	I_3	I_{31}	I_{311} I_{312} I_{313}	M	M	M	H	[0.3500,0.5625,0.7750]

			I_{314} I_{315}					
		I_{32}	I_{321} I_{322} I_{323} I_{324} I_{325}	H	H	VH	H	[0.5500,0.7750,1.0000]
		I_{33}	I_{331} I_{332} I_{333} I_{334}	H	M	H	VH	[0.5000,0.7125,0.9250]
4.	I_4	I_{41}	I_{411} I_{412} I_{413} I_{414}	M	H	H	M	[0.4000,0.6250,0.8500]
		I_{42}	I_{421} I_{422} I_{423} I_{424} I_{425} I_{426}	H	H	H	M	[0.4500,0.6875,0.9250]
5.	I_5	I_{51}	I_{511} I_{512} I_{513} I_{514} I_{515} I_{516} I_{517} I_{518}	VH	H	VH	H	[0.6000,0.8000,1.0000]
		I_{52}	I_{521} I_{522}	H	H	H	VH	[0.5500, 0.7750,1.0000]

Table 4.34: Weights of agile capabilities as suggested by experts (Level 1 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W)
1.	I_1	I_{11}	I_{111}	VH	H	H	VH	[0.6000, 0.8000, 1.0000]
			I_{112}					
			I_{113}					
			I_{114}					
			I_{115}					
			I_{116}					
			I_{117}					
		I_{12}	I_{121}					
			I_{122}					
			I_{123}					
			I_{124}					
		I_{13}	I_{131}					
			I_{132}					
			I_{133}					
			I_{134}					
			I_{135}					
2.	I_2	I_{21}	I_{211}	H	VH	H	H	[0.5500,0.7750,1.0000]
			I_{212}					
			I_{213}					
			I_{214}					
			I_{215}					
			I_{216}					
			I_{217}					
			I_{218}					
			I_{219}					
		I_{22}	I_{221}					
			I_{222}					
			I_{223}					
		I_{23}	I_{231}					
			I_{232}					
			I_{233}					
3.	I_3	I_{31}	I_{311}	VH	VH	H	H	[0.6000,0.8000,1.0000]
			I_{312}					

			I_{313}					
			I_{314}					
			I_{315}					
		I_{32}	I_{321}					
			I_{322}					
			I_{323}					
			I_{324}					
			I_{325}					
		I_{33}	I_{331}					
			I_{332}					
			I_{333}					
			I_{334}					
4.	I_4	I_{41}	I_{411}	H	VH	H	VH	[0.6000,0.8000,1.0000]
			I_{412}					
			I_{413}					
			I_{414}					
		I_{42}	I_{421}					
			I_{422}					
			I_{423}					
			I_{424}					
			I_{425}					
			I_{426}					
5.	I_5	I_{51}	I_{511}	H	VH	VH	VH	[0.6500,0.8250,1.0000]
			I_{512}					
			I_{513}					
			I_{514}					
			I_{515}					
			I_{516}					
			I_{517}					
			I_{518}					
		I_{52}	I_{521}					
			I_{522}					

Table 4.35: Ranking value for four set of decision-makers **(β=0.5169)**

$U_T(F_i)$	Ranking value
$U_T(F_1)$	0.3922
$U_T(F_2)$	0.4042
$U_T(F_3)$	0.4179
$U_T(F_4)$	0.3878

Case Study 2

Table 4.36: Membership functions for linguistic rating set S (β=0.2)

Linguistic Values	Fuzzy numbers
Very Good (VG)	(7,7.6,10)
Good (G)	(5,6,10)
Fair (F)	(3,3.8,7)
Poor (P)	(0,1,5)
Very Poor (VP)	(0,.6,3)

Table 4.37: Membership functions for linguistic weighting set W (β=0.2)

Linguistic Values	Fuzzy numbers
Very High (VH)	(.7,.76,1)
High (H)	(.5,.6,1)
Medium (M)	(.3,.38,.7)
Low (L)	(0,.1,.5)
Very Low (VL)	(0,.06,.3)

Table 4.38: Criteria rating assigned by experts (for Level 3 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4
1.	I_1	I_{11}	I_{111}	VP	VP	P	P
			I_{112}	P	F	P	F
			I_{113}	F	F	G	F
			I_{114}	F	P	G	P
			I_{115}	P	VG	VG	G
			I_{116}	F	F	VG	F
			I_{117}	F	VG	VG	G
		I_{12}	I_{121}	G	VG	G	VG
			I_{122}	F	G	G	G
			I_{123}	F	F	G	F
			I_{124}	G	F	G	G
		I_{13}	I_{131}	P	F	G	F
			I_{132}	F	VG	VG	G
			I_{133}	P	P	G	F
			I_{134}	F	F	VG	F
			I_{135}	G	G	F	P
2.	I_2	I_{21}	I_{211}	F	VG	G	F
			I_{212}	P	F	P	VP
			I_{213}	F	F	F	F
			I_{214}	P	P	F	VP
			I_{215}	G	G	G	F
			I_{216}	F	VG	F	G
			I_{217}	F	VG	G	F
			I_{218}	F	F	VP	F
			I_{219}	P	G	F	P
		I_{22}	I_{221}	G	VG	VG	VG
			I_{222}	F	F	G	F
			I_{223}	P	G	G	F
		I_{23}	I_{231}	F	VG	G	F
			I_{232}	P	G	P	F
			I_{233}	F	VG	G	F
3.	I_3	I_{31}	I_{311}	F	VG	G	F
			I_{312}	P	G	P	F
			I_{313}	G	G	F	P
			I_{314}	F	VG	F	F

			I_{315}	VG	VG	G	G
		I_{32}	I_{321}	G	G	VP	F
			I_{322}	P	G	F	F
			I_{323}	G	G	G	F
			I_{324}	F	VG	G	G
			I_{325}	G	VG	G	F
		I_{33}	I_{331}	G	VG	VG	VG
			I_{332}	VP	F	F	P
			I_{333}	P	F	P	F
			I_{334}	P	G	G	F
4.	I_4	I_{41}	I_{411}	G	VG	G	F
			I_{412}	F	G	G	G
			I_{413}	F	VG	VG	G
			I_{414}	G	VG	G	VG
		I_{42}	I_{421}	F	VG	VG	G
			I_{422}	P	G	G	F
			I_{423}	F	G	VG	G
			I_{424}	G	VG	VG	F
			I_{425}	G	VG	G	G
			I_{426}	F	VG	VG	VG
5.	I_5	I_{51}	I_{511}	G	VG	G	VG
			I_{512}	F	G	VG	VG
			I_{513}	P	G	VG	P
			I_{514}	F	VG	G	VG
			I_{515}	P	VG	VG	F
			I_{516}	F	G	G	VG
			I_{517}	G	VG	VG	F
			I_{518}	F	G	G	P
		I_{52}	I_{521}	F	VG	VG	F
			I_{522}	F	VG 7	VG	F

Table 4.39: Criteria weights as suggested by experts (for Level 3 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W_{ij})
1.	I_1	I_{11}	I_{111}	M	H	H	M	[0.4000, 0.4900,0.8500]
			I_{112}	VH	M	M	M	[0.4000,0.4750,0.7750]
			I_{113}	H	VH	H	H	[0.5500,0.6400,1.0000]
			I_{114}	H	M	M	VH	[0.4500,0.5300,0.8500]
			I_{115}	M	H	VH	H	[0.5000,0.5850,0.9250]
			I_{116}	M	VH	H	M	[0.4500,0.5300,0.8500]
			I_{117}	H	H	VH	VH	[0.6000,0.6800,1.0000]
		I_{12}	I_{121}	H	VH	H	VH	[0.6000,0.6800,1.0000]
			I_{122}	M	VH	M	H	[0.4500,0.5300,0.8500]
			I_{123}	M	M	H	VH	[0.4500,0.5300,0.8500]
			I_{124}	M	VH	VH	H	[0.5500,0.6250,0.9250]
		I_{13}	I_{131}	H	H	VH	H	[0.5500,0.6400,1.0000]
			I_{132}	M	H	H	VH	[0.5000,0.5850,0.9250]
			I_{133}	M	M	VH	M	[0.4000,0.4750,0.7750]
			I_{134}	VH	H	VH	M	[0.5500,0.6250,0.9250]
			I_{135}	M	M	H	H	[0.4000,0.4900,0.8500]
2.	I_2	I_{21}	I_{211}	M	H	VH	H	[0.5000,0.5850,0.9250]
			I_{212}	H	M	M	H	[0.4000,0.4900,0.8500]
			I_{213}	VH	H	VH	M	[0.5500,0.6250,0.9250]
			I_{214}	M	H	H	H	[0.4500,0.5450,0.9250]
			I_{215}	H	M	VH	VH	[0.5500,0.6250,0.9250]
			I_{216}	VH	VH	VH	H	[0.6500,0.7200,1.0000]
			I_{217}	H	VH	H	VH	[0.6000,0.6800,1.0000]
			I_{218}	M	H	VH	H	[0.5000,0.5850,0.9250]
			I_{219}	H	VH	H	H	[0.5500,0.6400,1.0000]
		I_{22}	I_{221}	M	H	VH	VH	[0.5500,0.6250,0.9250]
			I_{222}	H	VH	H	H	[0.5500,0.6400,1.0000]
			I_{223}	H	VH	M	H	[0.5000,0.5850,0.9250]
		I_{23}	I_{231}	M	H	H	H	[0.4500,0.5450,0.9250]
			I_{232}	H	M	VH	M	[0.4500,0.5300,0.8500]
			I_{233}	H	H	VH	H	[0.5500, 0.6400,1.0000]
3.	I_3	I_{31}	I_{311}	H	M	H	M	[0.4000,0.4900,0.8500]
			I_{312}	H	M	H	M	[0.4000,0.4900,0.8500]
			I_{313}	M	H	VH	H	[0.5000,0.5850,0.9250]

			I_{314}	M	M	H	VH	[0.4500,0.5300,0.8500]
			I_{315}	H	VH	H	H	[0.5500,0.6400,1.0000]
		I_{32}	I_{321}	M	H	H	H	[0.4500,0.5450,0.9250]
			I_{322}	M	M	VH	H	[0.4500 ,0.5300,0.8500]
			I_{323}	H	H	VH	VH	[0.6000,0.6800,1.0000]
			I_{324}	M	H	H	H	[0.4500,0.5450,0.9250]
			I_{325}	H	H	H	H	[0.5000,0.6000,1.0000]
		I_{33}	I_{331}	M	H	H	VH	[0.5000,0.5850,0.9250]
			I_{332}	M	VH	VH	M	[0.5000,0.5700,0.8500]
			I_{333}	H	H	M	H	[0.4500, 0.5450,0.9250]
			I_{334}	H	H	H	M	[0.4500,0.5450,0.9250]
4.	I_4	I_{41}	I_{411}	M	H	H	H	[0.4500,0.5450,0.9250]
			I_{412}	M	H	VH	H	[0.5000,0.5850,0.9250]
			I_{413}	H	VH	H	VH	[0.6000, 0.6800,1.0000]
			I_{414}	H	H	VH	VH	[0.6000 ,0.6800,1.0000]
		I_{42}	I_{421}	H	M	H	H	[0.4500,0.5450,0.9250]
			I_{422}	M	H	H	VH	[0.5000,0.5850,0.9250]
			I_{423}	H	M	VH	VH	[0.5500,0.6250,0.9250]
			I_{424}	VH	H	H	H	[0.5500, 0.6400,1.0000]
			I_{425}	H	H	VH	H	[0.5500,0.6400,1.0000]
			I_{426}	H	M	H	H	[0.4500,0.5450,0.9250]
5.	I_5	I_{51}	I_{511}	H	H	H	H	[0.5000,0.6000,1.0000]
			I_{512}	H	H	VH	H	[0.5500,0.6400,1.0000]
			I_{513}	H	VH	H	M	[0.5000,0.5850,0.9250]
			I_{514}	VH	VH	VH	VH	[0.7000,0.7600,1.0000]
			I_{515}	M	H	VH	H	[0.5000,0.5850,0.9250]
			I_{516}	VH	VH	H	VH	[0.6500,0.7200,1.0000]
			I_{517}	VH	VH	VH	H	[0.6500,0.7200,1.0000]
			I_{518}	VH	VH	VH	H	[0.6500,0.7200,1.0000]
		I_{52}	I_{521}	M	VH	H	H	[0.5000,0.5850,0.9250]
			I_{522}	M	VH	H	VH	[0.5500,0.6250,0.9250]

Table 4.40: Attribute weights as suggested by experts (for Level 2 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W_i)
1.	I_1	I_{11}	I_{111} I_{112} I_{113} I_{114} I_{115} I_{116} I_{117}	H	VH	VH	VH	[0.6500,0.7200,1.0000]
		I_{12}	I_{121} I_{122} I_{123} I_{124}	VH	H	VH	VH	[0.6500,0.7200,1.0000]
		I_{13}	I_{131} I_{132} I_{133} I_{134} I_{135}	M	M	H	H	[0.4000,0.4900,0.8500]
2.	I_2	I_{21}	I_{211} I_{212} I_{213} I_{214} I_{215} I_{216} I_{217} I_{218} I_{219}	H	VH	H	VH	[0.6000,0.6800,1.0000]
		I_{22}	I_{221} I_{222} I_{223}	VH	VH	H	H	[0.6000,0.6800,1.0000]
		I_{23}	I_{231} I_{232} I_{233}	M	H	VH	M	[0.4500,0.5300,0.8500]

3.	I_3	I_{31}	I_{311} I_{312} I_{313} I_{314} I_{315}	M	VH	M	H	[0.4500,0.5300,0.8500]
		I_{32}	I_{321} I_{322} I_{323} I_{324} I_{325}	M	H	VH	H	[0.5000,0.5850,0.9250]
		I_{33}	I_{331} I_{332} I_{333} I_{334}	H	VH	H	VH	[0.6000,0.6800,1.0000]
4.	I_4	I_{41}	I_{411} I_{412} I_{413} I_{414}	M	H	H	H	[0.4500,0.5450,0.9250]
		I_{42}	I_{421} I_{422} I_{423} I_{424} I_{425} I_{426}	H	H	H	M	[0.4500,0.5450,0.9250]
5.	I_5	I_{51}	I_{511} I_{512} I_{513} I_{514} I_{515} I_{516} I_{517} I_{518}	VH	H	VH	H	[0.6000,0.6800,1.0000]
		I_{52}	I_{521} I_{522}	H	H	H	VH	[0.5500,0.6400,1.0000]

Table 4.41: Weights of agile capabilities as suggested by experts (Level 1 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W)
1.	I_1	I_{11}	I_{111}	H	VH	H	VH	[0.6000,0.6800,1.0000]
			I_{112}					
			I_{113}					
			I_{114}					
			I_{115}					
			I_{116}					
			I_{117}					
		I_{12}	I_{121}					
			I_{122}					
			I_{123}					
			I_{124}					
		I_{13}	I_{131}					
			I_{132}					
			I_{133}					
			I_{134}					
			I_{135}					
2.	I_2	I_{21}	I_{211}	H	VH	H	H	[0.5500,0.6400,1.0000]
			I_{212}					
			I_{213}					
			I_{214}					
			I_{215}					
			I_{216}					
			I_{217}					
			I_{218}					
			I_{219}					
		I_{22}	I_{221}					
			I_{222}					
			I_{223}					
		I_{23}	I_{231}					
			I_{232}					
			I_{233}					

3.	I_3	I_{31}	I_{311}	VH	VH	VH	H	[0.6500,0.7200,1.0000]
			I_{312}					
			I_{313}					
			I_{314}					
			I_{315}					
		I_{32}	I_{321}					
			I_{322}					
			I_{323}					
			I_{324}					
			I_{325}					
		I_{33}	I_{331}					
			I_{332}					
			I_{333}					
			I_{334}					
4.	I_4	I_{41}	I_{411}	H	H	VH	VH	[0.6000,0.6800,1.0000]
			I_{412}					
			I_{413}					
			I_{414}					
		I_{42}	I_{421}					
			I_{422}					
			I_{423}					
			I_{424}					
			I_{425}					
			I_{426}					
5.	I_5	I_{51}	I_{511}	H	H	VH	VH	[0.6000,0.6800,1.0000]
			I_{512}					
			I_{513}					
			I_{514}					
			I_{515}					
			I_{516}					
			I_{517}					
			I_{518}					
		I_{52}	I_{521}					
			I_{522}					

Table 4.42: Ranking value for decision makers **(β= 0.2068)**

$U_T(F_i)$	Ranking value
$U_T(F_1)$	0.1394
$U_T(F_2)$	0.2120
$U_T(F_3)$	0.2011
$U_T(F_4)$	0.1622

Case Study 3

Table 4.43: Membership functions for linguistic rating set S (β=0.9)

Linguistic Values	Fuzzy numbers
Very Good (VG)	(7,9.7,10)
Good (G)	(5,9.5,10)
Fair (F)	(3,6.6,7)
Poor (P)	(0,4.5,5)
Very Poor (VP)	(0,.2.7,3)

Table 4.44: Membership functions for linguistic Weighting set W (β=0.9)

Linguistic Values	Fuzzy numbers
Very High (VH)	(.7,.97,1)
High (H)	(.5,.95,1)
Medium (M)	(.3,.66,.7)
Low (L)	(0,.45,.5)
Very Low (VL)	(0,.27,.3)

Table 4.45: Criteria rating assigned by experts (for Level 3 index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4
1.	I_1	I_{11}	I_{111}	F	P	VP	P
			I_{112}	F	F	P	F
			I_{113}	F	P	F	G
			I_{114}	G	F	F	F
			I_{115}	G	VG	G	G
			I_{116}	F	G	F	G
			I_{117}	G	VG	G	G
		I_{12}	I_{121}	VG	VG	G	VG
			I_{122}	F	G	F	G
			I_{123}	G	G	F	G
			I_{124}	VG	F	F	VG
		I_{13}	I_{131}	G	F	F	G
			I_{132}	VG	G	G	G
			I_{133}	F	VP	F	F
			I_{134}	G	F	F	G
			I_{135}	G	F	F	G
2.	I_2	I_{21}	I_{211}	VG	G	F	F
			I_{212}	F	F	P	VP
			I_{213}	F	F	P	G
			I_{214}	P	P	F	P
			I_{215}	G	F	F	F
			I_{216}	F	G	F	G
			I_{217}	G	G	F	G
			I_{218}	F	F	P	F
			I_{219}	F	VP	P	P
		I_{22}	I_{221}	VG	VG	G	VG
			I_{222}	G	F	F	F
			I_{223}	P	F	P	F
		I_{23}	I_{231}	F	G	G	F
			I_{232}	P	VP	P	F
			I_{233}	G	G	G	G
3.	I_3	I_{31}	I_{311}	G	G	F	G
			I_{312}	P	F	P	F

			I_{313}	F	G	F	P
			I_{314}	G	F	G	F
			I_{315}	VG	G	F	G
		I_{32}	I_{321}	F	P	VP	F
			I_{322}	P	F	F	P
			I_{323}	G	F	G	F
			I_{324}	G	G	F	G
			I_{325}	G	VG	G	F
		I_{33}	I_{331}	G	G	VG	VG
			I_{332}	P	P	P	VP
			I_{333}	VP	P	VP	VP
			I_{334}	F	P	F	F
4.	I_4	I_{41}	I_{411}	G	F	F	F
			I_{412}	G	F	G	F
			I_{413}	VG	VG	VG	G
			I_{414}	G	VG	G	VG
		I_{42}	I_{421}	F	G	F	F
			I_{422}	P	F	P	F
			I_{423}	G	G	G	G
			I_{424}	VG	G	VG	VG
			I_{425}	G	VG	G	VG
			I_{426}	G	F	G	F
5.	I_5	I_{51}	I_{511}	VG	G	VG	VG
			I_{512}	F	G	G	G
			I_{513}	P	F	P	F
			I_{514}	G	VG	G	G
			I_{515}	F	P	F	F
			I_{516}	G	VG	G	VG
			I_{517}	VG	VG	VG	G
			I_{518}	G	G	G	VG
		I_{52}	I_{521}	VG	G	VG	G
			I_{522}	VG	G	VG	VG

Table 4.46: Criteria weights as suggested by experts (for Level 3 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W_{ij})
1.	I_1	I_{11}	I_{111}	H	H	H	M	[0.4500, 0.8775, 0.9250]
			I_{112}	VH	M	M	M	[0.4000, 0.7375, 0.7750]
			I_{113}	H	VH	H	H	[0.5500, 0.9550, 1.0000]
			I_{114}	H	M	M	VH	[0.4500, 0.8100, 0.8500]
			I_{115}	M	H	VH	H	[0.5000, 0.8825, 0.9250]
			I_{116}	M	VH	H	M	[0.4500 , 0.8100, 0.8500]
			I_{117}	H	H	VH	VH	[0.6000, 0.9600, 1.0000]
		I_{12}	I_{121}	H	VH	H	VH	[0.6000, 0.9600, 1.0000]
			I_{122}	VH	VH	M	H	[0.5500 , 0.8875, 0.9250]
			I_{123}	M	M	H	VH	[0.4500 , 0.8100, 0.8500]
			I_{124}	H	VH	VH	H	[0.6000, 0.9600, 1.0000]
		I_{13}	I_{131}	VH	H	VH	H	[0.6000, 0.9600, 1.0000]
			I_{132}	M	H	H	VH	[0.5000, 0.8825, 0.9250]
			I_{133}	M	M	H	M	[0.3500, 0.7325, 0.7750]
			I_{134}	VH	H	VH	H	[0.6000, 0.9600, 1.0000]
			I_{135}	M	M	H	H	[0.4000, 0.8050, 0.8500]
2.	I_2	I_{21}	I_{211}	VH	H	H	VH	[0.6000, 0.9600, 1.0000]
			I_{212}	H	M	M	H	[0.4000, 0.8050, 0.8500]
			I_{213}	VH	H	VH	M	[0.5500, 0.8875, 0.9250]
			I_{214}	H	M	H	H	[0.4500, 0.8775, 0.9250]
			I_{215}	H	M	VH	VH	[0.5500, 0.8875, 0.9250]
			I_{216}	VH	VH	H	H	[0.6000, 0.9600 , 1.0000]
			I_{217}	H	H	H	VH	[0.5500, 0.9550 , 1.0000]
			I_{218}	M	H	VH	H	[0.5000, 0.8825 , 0.9250]
			I_{219}	H	VH	H	VH	[0.6000, 0.9600, 1.0000]
		I_{22}	I_{221}	VH	H	VH	VH	[0.6500, 0.9650, 1.0000]
			I_{222}	H	VH	H	H	[0.5500, 0.9550, 1.0000]
			I_{223}	VH	H	M	H	[0.5000, 0.8825, 0.9250]
		I_{23}	I_{231}	M	H	M	H	[0.4000, 0.8050, 0.8500]
			I_{232}	H	M	H	M	[0.4000 , 0.8050, 0.8500]
			I_{233}	H	H	VH	H	[0.5500 , 0.9550, 1.0000]
3.	I_3	I_{31}	I_{311}	H	M	H	M	[0.4000, 0.8050, 0.8500]

			I_{312}	H	M	H	M	[0.4000,	0.8050,	0.8500]
			I_{313}	VH	H	VH	H	[0.6000,	0.9600,	1.0000]
			I_{314}	M	M	M	VH	[0.4000,	0.7375,	0.7750]
			I_{315}	H	VH	H	H	[0.5500,	0.9550,	1.0000]
		I_{32}	I_{321}	M	H	H	H	[0.4500,	0.8775,	0.9250]
			I_{322}	M	M	VH	H	[0.4500,	0.8100,	0.8500]
			I_{323}	H	H	VH	VH	[0.6000,	0.9600,	1.0000]
			I_{324}	M	H	H	H	[0.6000,	0.9600,	1.0000]
			I_{325}	H	M	H	H	[0.4500,	0.8775,	0.9250]
		I_{33}	I_{331}	M	H	H	VH	[0.5000,	0.8825,	0.9250]
			I_{332}	M	VH	VH	M	[0.5000,	0.8150,	0.8500]
			I_{333}	H	H	M	H	[0.4500,	0.8775,	0.9250]
			I_{334}	H	H	H	M	[0.4500,	0.8775 ,	0.9250]
4.	I_4	I_{41}	I_{411}	M	H	H	H	[0.4500,	0.8775,	0.9250]
			I_{412}	M	H	VH	H	[0.5000,	0.8825,	0.9250]
			I_{413}	H	VH	H	VH	[0.6000,	0.9600,	1.0000]
			I_{414}	H	H	VH	VH	[0.6000,	0.9600,	1.0000]
		I_{42}	I_{421}	H	M	H	H	[0.4500,	0.8775,	0.9250]
			I_{422}	M	H	H	VH	[0.5000,	0.8825,	0.9250]
			I_{423}	H	M	VH	VH	[0.5500,	0.8875,	0.9250]
			I_{424}	VH	H	H	H	[0.5500,	0.9550,	1.0000]
			I_{425}	H	H	VH	H	[0.5500,	0.9550,	1.0000]
			I_{426}	H	M	H	H	[0.4500,	0.8775,	0.9250]
5.	I_5	I_{51}	I_{511}	M	H	H	H	[0.4500,	0.8775,	0.9250]
			I_{512}	VH	H	VH	H	[0.6000,	0.9600,	1.0000]
			I_{513}	H	VH	H	M	[0.5000,	0.8825,	0.9250]
			I_{514}	M	H	VH	VH	[0.5500 ,	0.8875,	0.9250]
			I_{515}	M	M	H	H	[0.4000,	0.8050 ,	0.8500]
			I_{516}	H	VH	H	VH	[0.6000,	0.9600 ,	1.0000]
			I_{517}	VH	H	VH	H	[0.6000 ,	0.9600 ,	1.0000]
			I_{518}	VH	H	VH	H	[0.6000 ,	0.9600 ,	1.0000]
		I_{52}	I_{521}	H	M	H	H	[0.4500 ,	0.8775 ,	0.9250]
			I_{522}	H	VH	H	VH	[0.6000 ,	0.9600 ,	1.0000]

Table 4.47: Attribute weights as suggested by experts (for Level 2 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W_i)
1.	I_1	I_{11}	I_{111} I_{112} I_{113} I_{114} I_{115} I_{116} I_{117}	M	H	H	M	[0.4000, 0.8050 0.8500]
		I_{12}	I_{121} I_{122} I_{123} I_{124}	VH	H	VH	H	[0.6000, 0.9600 1.0000]
		I_{13}	I_{131} I_{132} I_{133} I_{134} I_{135}	M	M	H	H	[0.4000,0.8050 0.8500]
2.	I_2	I_{21}	I_{211} I_{212} I_{213} I_{214} I_{215} I_{216} I_{217} I_{218} I_{219}	H	H	H	VH	[0.5500,0.9550, 1.0000]
		I_{22}	I_{221} I_{222} I_{223}	VH	VH	H	H	[0.6000, 0.9600 ,1.0000]
		I_{23}	I_{231} I_{232} I_{233}	H	M	H	H	[0.4500, 0.8775,0.9250]
3.	I_3	I_{31}	I_{311}	M7	H	M	H	[0.4000, 0.8050, 0.8500]

			I_{312}					
			I_{313}					
			I_{314}					
			I_{315}					
		I_{32}	I_{321}	H	H	VH	H	[0.5500, 0.9550,1.0000]
			I_{322}					
			I_{323}					
			I_{324}					
			I_{325}					
		I_{33}	I_{331}	H	M	H	M	[0.4000, 0.8050, 0.8500]
			I_{332}					
			I_{333}					
			I_{334}					
4.	I_4	I_{41}	I_{411}	M	H	M	M	[0.3500, 0.7325, 0.7750]
			I_{412}					
			I_{413}					
			I_{414}					
		I_{42}	I_{421}	H	H	H	M	[0.4500, 0.8775, 0.9250]
			I_{422}					
			I_{423}					
			I_{424}					
			I_{425}					
			I_{426}					
5.	I_5	I_{51}	I_{511}	VH	H	VH	H	[0.6000, 0.9600, 1.0000]
			I_{512}					
			I_{513}					
			I_{514}					
			I_{515}					
			I_{516}					
			I_{517}					
			I_{518}					
		I_{52}	I_{521}	H	H	H	VH	[0.5500, 0.9550,1.0000]
			I_{522}					

Table 4.48: Weights of agile capabilities as suggested by experts (for Level 1 Index)

Sl. No.	Level 1 index	Level 2 index	Level 3 index	DM_1	DM_2	DM_3	DM_4	Avg (W)
1.	I_1	I_{11}	I_{111}	VH	H	H	VH	[0.6000, 0.9600,1.0000]
			I_{112}					
			I_{113}					
			I_{114}					
			I_{115}					
			I_{116}					
			I_{117}					
		I_{12}	I_{121}					
			I_{122}					
			I_{123}					
			I_{124}					
		I_{13}	I_{131}					
			I_{132}					
			I_{133}					
			I_{134}					
			I_{135}					
2.	I_2	I_{21}	I_{211}	H	VH	H	VH	[0.6000 , 0.9600,1.0000]
			I_{212}					
			I_{213}					
			I_{214}					
			I_{215}					
			I_{216}					
			I_{217}					
			I_{218}					
			I_{219}					
		I_{22}	I_{221}					
			I_{222}					
			I_{223}					
		I_{23}	I_{231}					
			I_{232}					
			I_{233}					

3.	I_3	I_{31}	I_{311}	VH	H	H	VH	[0.6000, 0.9600,1.0000]
			I_{312}					
			I_{313}					
			I_{314}					
			I_{315}					
		I_{32}	I_{321}					
			I_{322}					
			I_{323}					
			I_{324}					
			I_{325}					
		I_{33}	I_{331}					
			I_{332}					
			I_{333}					
			I_{334}					
4.	I_4	I_{41}	I_{411}	H	VH	VH	H	[0.6000, 0.9600 ,1.0000]
			I_{412}					
			I_{413}					
			I_{414}					
		I_{42}	I_{421}					
			I_{422}					
			I_{423}					
			I_{424}					
			I_{425}					
			I_{426}					
5.	I_5	I_{51}	I_{511}	VH	H	VH	VH	[0.6500, 0.9650,1.0000]
			I_{512}					
			I_{513}					
			I_{514}					
			I_{515}					
			I_{516}					
			I_{517}					
			I_{518}					
		I_{52}	I_{521}					
			I_{522}					

Table 4.49: Ranking value for decision makers **(β= 0.9304)**

$U_T(F_i)$	Ranking value
$U_T(F_1)$	0.8178
$U_T(F_2)$	0.7888
$U_T(F_3)$	0.7468
$U_T(F_4)$	0.8008

CHAPTER 5: Additional Data Tables

Table 5.3: Priority weights of sub-criteria (3rd Level) assigned by the DMs using linguistic terms

$C_{i,j}$	Subjective priority weights given by the DMs				
	DM_1	DM_2	DM_3	DM_4	DM_5
$C_{1,1}$	AH	AH	AH	AH	VH
$C_{1,2}$	H	H	H	VH	VH
$C_{1,3}$	MH	H	MH	MH	H
$C_{1,4}$	H	H	H	H	H
$C_{1,5}$	AH	AH	AH	AH	AH
$C_{1,6}$	H	H	VH	VH	VH
$C_{1,7}$	VH	VH	VH	VH	VH
$C_{1,8}$	H	H	H	MH	MH
$C_{1,9}$	AH	AH	VH	VH	VH
$C_{1,10}$	AH	AH	AH	AH	AH
$C_{1,11}$	H	MH	MH	MH	H
$C_{1,12}$	VH	VH	H	H	H
$C_{1,13}$	AH	AH	AH	AH	VH
$C_{1,14}$	H	H	H	VH	VH
$C_{1,15}$	MH	H	MH	MH	H
$C_{1,16}$	H	H	H	H	H
$C_{1,17}$	AH	AH	AH	AH	AH
$C_{1,18}$	H	H	VH	VH	VH
$C_{1,19}$	VH	VH	VH	VH	VH
$C_{1,20}$	AH	AH	AH	AH	AH
$C_{1,21}$	H	H	VH	VH	VH
$C_{1,22}$	VH	VH	VH	VH	VH
$C_{1,23}$	H	H	H	MH	MH
$C_{1,24}$	AH	AH	VH	VH	VH
$C_{1,25}$	AH	AH	AH	AH	AH
$C_{1,26}$	H	MH	MH	MH	H
$C_{2,1}$	VH	VH	AH	VH	VH
$C_{2,2}$	H	H	H	H	H
$C_{2,3}$	H	H	H	H	H
$C_{2,4}$	H	H	H	H	H
$C_{2,5}$	VH	VH	VH	VH	VH
$C_{2,6}$	VH	VH	VH	VH	VH
$C_{2,7}$	VH	VH	VH	VH	VH
$C_{2,8}$	VH	VH	VH	VH	VH
$C_{2,9}$	AH	AH	AH	AH	AH
$C_{2,10}$	H	H	VH	VH	VH
$C_{2,11}$	VH	VH	VH	VH	VH
$C_{2,12}$	AH	AH	AH	AH	AH
$C_{2,13}$	H	H	VH	VH	VH
$C_{2,14}$	VH	VH	VH	VH	VH
$C_{2,15}$	VH	VH	VH	VH	VH
$C_{2,16}$	AH	AH	AH	AH	VH
$C_{2,17}$	H	H	H	H	VH

$C_{2,18}$	VH	VH	VH	VH	VH
$C_{2, 19}$	AH	VH	VH	AH	AH
$C_{2,20}$	VH	H	H	H	VH
$C_{2,21}$	AH	AH	AH	AH	VH
$C_{2,22}$	VH	VH	VH	VH	VH
$C_{3,1}$	AH	VH	VH	AH	AH
$C_{3,2}$	VH	VH	VH	VH	VH
$C_{3,3}$	AH	VH	VH	AH	AH
$C_{3,4}$	VH	H	H	H	VH
$C_{3,5}$	AH	AH	AH	AH	VH
$C_{3,6}$	VH	VH	VH	VH	VH
$C_{3,7}$	AH	AH	AH	AH	VH
$C_{3,8}$	AH	VH	VH	AH	AH
$C_{3,9}$	VH	H	H	H	VH
$C_{3,10}$	AH	VH	VH	AH	AH
$C_{3,11}$	VH	H	H	H	VH
$C_{3,12}$	H	H	H	H	H
$C_{3,13}$	H	H	H	H	H
$C_{3,14}$	VH	VH	VH	VH	VH
$C_{4,1}$	AH	AH	AH	AH	AH
$C_{4,2}$	AH	AH	AH	AH	AH
$C_{4,3}$	AH	AH	AH	AH	AH
$C_{4,4}$	AH	AH	AH	AH	AH
$C_{4,5}$	AH	AH	AH	AH	AH
$C_{4,6}$	AH	AH	AH	AH	AH
$C_{4,7}$	VH	H	H	H	VH
$C_{4,8}$	AH	VH	VH	AH	AH
$C_{4,9}$	VH	H	H	H	VH
$C_{4,10}$	AH	AH	AH	AH	VH
$C_{4,11}$	VH	VH	VH	VH	VH
$C_{4,12}$	AH	AH	AH	AH	VH
$C_{4,13}$	H	H	H	H	H
$C_{4,14}$	AH	VH	VH	AH	AH
$C_{5,1}$	VH	H	H	H	VH
$C_{5,2}$	AH	AH	AH	AH	VH
$C_{5,3}$	VH	VH	VH	VH	VH
$C_{5,4}$	AH	AH	AH	AH	VH
$C_{5,5}$	H	H	H	H	VH
$C_{5,6}$	VH	VH	VH	VH	VH
$C_{5,7}$	AH	VH	VH	AH	AH
$C_{5,8}$	VH	H	H	H	VH
$C_{5,9}$	AH	VH	VH	AH	AH
$C_{5,10}$	VH	H	H	H	VH
$C_{5,11}$	AH	AH	AH	AH	VH
$C_{5,12}$	VH	VH	VH	VH	VH
$C_{5,13}$	AH	AH	AH	AH	VH
$C_{5,14}$	H	H	H	H	VH
$C_{5,16}$	VH	VH	VH	VH	VH
$C_{5,17}$	AH	VH	VH	AH	AH

$C_{5,18}$	VH	H	H	H	VH
$C_{5,19}$	AH	AH	AH	AH	VH
$C_{5,20}$	VH	VH	VH	VH	VH
$C_{6,1}$	AH	VH	VH	AH	AH
$C_{6,2}$	VH	H	H	H	VH
$C_{6,3}$	AH	AH	AH	AH	VH
$C_{6,4}$	VH	VH	VH	VH	VH
$C_{6,5}$	AH	AH	AH	AH	VH
$C_{6,6}$	H	H	H	H	VH
$C_{6,7}$	AH	VH	VH	AH	AH
$C_{6,8}$	VH	H	H	H	VH
$C_{6,9}$	AH	AH	AH	AH	VH
$C_{6,10}$	VH	VH	VH	VH	VH
$C_{6,11}$	AH	AH	AH	AH	VH
$C_{6,12}$	H	H	H	H	VH
$C_{6,13}$	AH	VH	VH	AH	AH
$C_{7,1}$	VH	H	H	H	VH
$C_{7,2}$	AH	AH	AH	AH	VH
$C_{7,3}$	VH	VH	VH	VH	VH
$C_{7,4}$	AH	AH	AH	AH	VH
$C_{7,5}$	AH	VH	VH	AH	AH
$C_{7,6}$	VH	H	H	H	VH
$C_{7,7}$	AH	AH	AH	AH	VH
$C_{7,8}$	VH	VH	VH	VH	VH

Table 5.4: Priority weights of main criteria (2nd Level) assigned by the DMs using linguistic terms

C_i	Subjective priority weights given by the DMs				
	DM_1	DM_2	DM_3	DM_4	DM_5
C_1	AH	VH	VH	AH	AH
C_2	VH	H	H	H	VH
C_3	AH	AH	AH	AH	VH
C_4	VH	VH	VH	VH	VH
C_5	AH	AH	AH	AH	VH
C_6	H	H	H	H	VH
C_7	VH	VH	VH	VH	VH

Table 5.5: Rating of sub-criteria (3rd Level) assigned by the DMs using linguistic terms

C_i	$C_{i,j}$	Subjective rating assigned by the DMs				
		DM_1	DM_2	DM_3	DM_4	DM_5
C_1	$C_{1,1}$	VG	G	G	AG	AG
	$C_{1,2}$	AG	AG	AG	VG	VG
	$C_{1,3}$	MG	MG	G	G	G
	$C_{1,4}$	VG	VG	G	G	VG
	$C_{1,5}$	G	G	G	VG	VG
	$C_{1,6}$	G	G	MG	MG	MG
	$C_{1,7}$	VG	VG	G	G	VG
	$C_{1,8}$	MG	M	M	M	MG
	$C_{1,9}$	G	G	G	VG	G
	$C_{1,10}$	G	G	G	MG	MG
	$C_{1,11}$	G	G	G	G	G
	$C_{1,12}$	MG	M	MG	MG	M
	$C_{1,13}$	AG	AG	VG	VG	VG
	$C_{1,14}$	G	MG	G	G	G
	$C_{1,15}$	VG	VG	AG	AG	VG
	$C_{1,16}$	G	G	G	G	MG
	$C_{1,17}$	G	G	VG	G	MG
	$C_{1,18}$	VG	VG	G	G	VG
	$C_{1,19}$	VG	VG	VG	AG	AG
	$C_{1,20}$	G	G	G	G	MG
	$C_{1,21}$	MP	M	M	M	G
	$C_{1,22}$	VG	VG	G	G	VG
	$C_{1,23}$	MG	M	M	M	MG
	$C_{1,24}$	G	G	G	VG	G
	$C_{1,25}$	VG	G	G	AG	AG
	$C_{1,26}$	AG	AG	AG	VG	VG
C_2	$C_{2,1}$	VG	VG	G	G	VG
	$C_{2,2}$	VG	VG	VG	AG	AG
	$C_{2,3}$	G	G	G	G	MG
	$C_{2,4}$	VG	VG	G	G	G
	$C_{2,5}$	MG	M	MG	MG	M
	$C_{2,6}$	AG	AG	VG	VG	VG
	$C_{2,7}$	G	MG	G	G	G
	$C_{2,8}$	VG	VG	AG	AG	VG
	$C_{2,9}$	G	G	G	G	MG
	$C_{2,10}$	MG	M	MG	MG	M
	$C_{2,11}$	VG	VG	G	G	G
	$C_{2,12}$	AG	AG	AG	VG	VG
	$C_{2,13}$	MG	M	MG	MG	M
	$C_{2,14}$	AG	AG	VG	VG	VG
	$C_{2,15}$	G	MG	G	G	G
	$C_{2,16}$	VG	VG	AG	AG	VG
	$C_{2,17}$	MP	P	P	MP	MP
	$C_{2,18}$	M	M	MG	MG	MG
	$C_{2,19}$	G	G	G	G	G

	$C_{2,20}$	G	G	G	VG	VG
	$C_{2,21}$	G	G	MG	MG	G
	$C_{2,22}$	VG	VG	VG	G	G
C_3	$C_{3,1}$	VG	G	G	AG	AG
	$C_{3,2}$	AG	AG	AG	VG	VG
	$C_{3,3}$	MG	MG	G	G	G
	$C_{3,4}$	VG	VG	G	G	VG
	$C_{3,5}$	G	G	G	VG	VG
	$C_{3,6}$	G	G	MG	MG	MG
	$C_{3,7}$	VG	VG	G	G	VG
	$C_{3,8}$	MG	M	M	M	MG
	$C_{3,9}$	G	G	G	VG	G
	$C_{3,10}$	G	G	G	MG	MG
	$C_{3,11}$	G	G	G	G	G
	$C_{3,12}$	MG	M	MG	MG	M
	$C_{3,13}$	AG	AG	VG	VG	VG
	$C_{3,14}$	G	MG	G	G	G
C_4	$C_{4,1}$	VG	VG	AG	AG	VG
	$C_{4,2}$	G	G	G	G	MG
	$C_{4,3}$	G	G	VG	G	MG
	$C_{4,4}$	VG	VG	G	G	VG
	$C_{4,5}$	VG	VG	VG	AG	AG
	$C_{4,6}$	G	G	G	G	MG
	$C_{4,7}$	VG	VG	AG	AG	VG
	$C_{4,8}$	VG	VG	G	G	VG
	$C_{4,9}$	MG	M	M	M	MG
	$C_{4,10}$	G	G	G	VG	G
	$C_{4,11}$	G	G	G	MG	MG
	$C_{4,12}$	G	G	G	G	G
	$C_{4,13}$	MG	M	MG	MG	M
	$C_{4,14}$	AG	AG	VG	VG	VG
C_5	$C_{5,1}$	VG	G	G	AG	AG
	$C_{5,2}$	AG	AG	AG	VG	VG
	$C_{5,3}$	MG	MG	G	G	G
	$C_{5,4}$	VG	VG	G	G	VG
	$C_{5,5}$	G	G	G	VG	VG
	$C_{5,6}$	MP	P	P	MP	MP
	$C_{5,7}$	M	M	MG	MG	MG
	$C_{5,8}$	G	G	G	G	G
	$C_{5,9}$	G	G	G	VG	VG
	$C_{5,10}$	G	G	MG	MG	G
	$C_{5,11}$	VG	VG	G	G	VG
	$C_{5,12}$	MG	M	MG	MG	M
	$C_{5,13}$	VG	VG	G	G	G
	$C_{5,14}$	AG	AG	AG	VG	VG
	$C_{5,16}$	MG	M	MG	MG	M
	$C_{5,17}$	AG	AG	VG	VG	VG
	$C_{5,18}$	G	MG	G	G	G
	$C_{5,19}$	VG	VG	AG	AG	VG

	$C_{5,20}$	G	G	VG	VG	G
C_6	$C_{6,1}$	MG	MG	G	G	G
	$C_{6,2}$	MG	M	MG	MG	M
	$C_{6,3}$	G	G	G	VG	VG
	$C_{6,4}$	G	G	MG	MG	G
	$C_{6,5}$	VG	VG	G	G	VG
	$C_{6,6}$	VG	VG	G	G	VG
	$C_{6,7}$	G	G	G	VG	VG
	$C_{6,8}$	AG	AG	VG	VG	VG
	$C_{6,9}$	VG	VG	G	G	VG
	$C_{6,10}$	MG	M	M	M	MG
	$C_{6,11}$	G	G	G	VG	G
	$C_{6,12}$	G	G	G	MG	MG
	$C_{6,13}$	G	G	G	G	G
C_7	$C_{7,1}$	M	M	MG	MG	MG
	$C_{7,2}$	G	G	G	G	G
	$C_{7,3}$	MG	MG	G	G	G
	$C_{7,4}$	VG	VG	G	G	VG
	$C_{7,5}$	VG	VG	G	G	VG
	$C_{7,6}$	MG	M	M	M	MG
	$C_{7,7}$	G	G	G	VG	G
	$C_{7,8}$	G	G	G	MG	MG

Table 5.6: Aggregated ratings and weights of sub-criteria (3rd Level) in terms of fuzzy numbers

Criteria	Sub-criteria	Aggregated rating	Aggregated weight
C_1	$C_{1,1}$	(0.75, 0.8125, 0.875, 0.9375)	(0.85, 0.9125, 0.975,0.9875)
	$C_{1,2}$	(0.825, 0.8875, 0.95, 0.975)	(0.675, 0.7375, 0.8, 0.8625)
	$C_{1,3}$	(0.575, 0.6375, 0.700, 0.7625)	(0.55, 0.6125, 0.675, 0.7375)
	$C_{1,4}$	(0.7, 0.7625, 0.825, 0.8875)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{1,5}$	(0.675, 0.7375, 0.800, 0.8625)	(0.875, 0.9375, 1, 1)
	$C_{1,6}$	(0.55, 0.6125, 0.675, 0.7375)	(0.7, 0.7625, 0.825, 0.8875)
	$C_{1,7}$	(0.675, 0.7375, 0.800, 0.8625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{1,8}$	(0.4625, 0.525, 0.55, 0.6125)	(0.575, 0.6375, 0.7, 0.7625)
	$C_{1,9}$	(0.65, 0.7125, 0.775, 0.8375)	(0.8, 0.8625, 0.925, 0.9625)
	$C_{1,10}$	(0.575, 0.6375, 0.700, 0.7625)	(0.875, 0.9375, 1, 1)
	$C_{1,11}$	(0.625, 0.6875, 0.75, 0.8125)	(0.55, 0.6125, 0.675, 0.7375)
	$C_{1,12}$	(0.475, 0.5375, 0.575, 0.6375)	(0.675, 0.7375, 0.8, 0.8625)
	$C_{1,13}$	(0.800, 0.8625, 0.925, 0.9625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{1,14}$	(0.600, 0.6625, 0.725, 0.7875)	(0.675, 0.7375, 0.8, 0.8625)
	$C_{1,15}$	(0.800, 0.8625, 0.925, 0.9625)	(0.55, 0.6125, 0.675, 0.7375)
	$C_{1,16}$	(0.600, 0.6625, 0.725, 0.7875)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{1,17}$	(0.625, 0.6875, 0.75, 0.8125)	(0.875, 0.9375, 1, 1)
	$C_{1,18}$	(0.7, 0.7625, 0.825, 0.8875)	(0.7, 0.7625, 0.825, 0.8875)
	$C_{1,19}$	(0.8, 0.8625, 0.925, 0.9625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{1,20}$	(0.6, 0.6625, 0.725, 0.7875)	(0.875, 0.9375, 1, 1)

	$C_{1,21}$	(0.45, 0.5125, 0.5375, 0.6)	(0.7, 0.7625, 0.825, 0.8875)
	$C_{1,22}$	(0.7, 0.7625, 0.825, 0.8875)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{1,23}$	(0.4625, 0.525, 0.55, 0.6125)	(0.575, 0.6375, 0.7, 0.7625)
	$C_{1,24}$	(0.65, 0.7125, 0.775, 0.8375)	(0.8, 0.8625, 0.925, 0.9625)
	$C_{1,25}$	(0.75, 0.8125, 0.875, 0.9375)	(0.875, 0.9375, 1, 1)
	$C_{1,26}$	(0.825, 0.8875, 0.95, 0.975)	(0.55, 0.6125, 0.675, 0.7375)
C_2	$C_{2,1}$	(0.7, 0.7625, 0.825, 0.8875)	(0.775, 0.8375, 0.900, 0.950)
	$C_{2,2}$	(0.8, 0.8625, 0.925, 0.9625)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{2,3}$	(0.6, 0.6625, 0.725, 0.7875)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{2,4}$	(0.675, 0.7375, 0.8, 0.8625)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{2,5}$	(0.475, 0.5375, 0.575, 0.6375)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,6}$	(0.8, 0.8625, 0.925, 0.9625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,7}$	(0.6, 0.6625, 0.725, 0.7875)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,8}$	(0.8, 0.8625, 0.925, 0.9625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,9}$	(0.6, 0.6625, 0.725, 0.7875)	(0.875, 0.9375, 1, 1)
	$C_{2,10}$	(0.475, 0.5375, 0.575, 0.6375)	(0.7, 0.7625, 0.825, 0.8875)
	$C_{2,11}$	(0.675, 0.7375, 0.8, 0.8625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,12}$	(0.825, 0.8875, 0.95, 0.975)	(0.875, 0.9375, 1, 1)
	$C_{2,13}$	(0.475, 0.5375, 0.575, 0.6375)	(0.7, 0.7625, 0.825, 0.8875)
	$C_{2,14}$	(0.8, 0.8625, 0.925, 0.9625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,15}$	(0.6, 0.6625, 0.725, 0.7875)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,16}$	(0.8, 0.8625, 0.925, 0.9625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{2,17}$	(0.2625, 0.325, 0.3875, 0.45)	(0.65, 0.7125, 0.775, 0.8375)
	$C_{2,18}$	(0.475, 0.5375, 0.575, 0.6375)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{2,19}$	(0.625, 0.6875, 0.75, 0.8125)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{2,20}$	(0.675, 0.7375, 0.8, 0.8625)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{2,21}$	(0.575, 0.6375, 0.7, 0.7625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{2,22}$	(0.7, 0.7625, 0.825, 0.8875)	(0.75, 0.8125, 0.875, 0.9375)
C_3	$C_{3,1}$	(0.75, 0.8125, 0.875, 0.9375)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{3,2}$	(0.825, 0.8875, 0.95, 0.975)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{3,3}$	(0.575, 0.6375, 0.7, 0.7625)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{3,4}$	(0.7, 0.7625, 0.825, 0.8875)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{3,5}$	(0.675, 0.7375, 0.8, 0.8625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{3,6}$	(0.55, 0.6125, 0.675, 0.7375)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{3,7}$	(0.675, 0.7375, 0.8, 0.8625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{3,8}$	(0.4625, 0.525, 0.55, 0.6125)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{3,9}$	(0.65, 0.7125, 0.775, 0.8375)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{3,10}$	(0.575, 0.6375, 0.7, 0.7625)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{3,11}$	(0.625, 0.6875, 0.75, 0.8125)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{3,12}$	(0.475, 0.5375, 0.575, 0.6375)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{3,13}$	(0.8, 0.8625, 0.925, 0.9625)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{3,14}$	(0.6, 0.6625, 0.725, 0.7875)	(0.75, 0.8125, 0.875, 0.9375)
C_4	$C_{4,1}$	(0.8, 0.8625, 0.925, 0.9625)	(0.875, 0.9375, 1, 1)
	$C_{4,2}$	(0.6, 0.6625, 0.725, 0.7875)	(0.875, 0.9375, 1, 1)
	$C_{4,3}$	(0.625, 0.6875, 0.75, 0.8125)	(0.875, 0.9375, 1, 1)
	$C_{4,4}$	(0.7, 0.7625, 0.825, 0.8875)	(0.875, 0.9375, 1, 1)
	$C_{4,5}$	(0.8, 0.8625, 0.925, 0.9625)	(0.875, 0.9375, 1, 1)
	$C_{4,6}$	(0.6, 0.6625, 0.725, 0.7875)	(0.875, 0.9375, 1, 1)
	$C_{4,7}$	(0.8, 0.8625, 0.925, 0.9625)	(0.675, 0.7375, 0.800, 0.8625)

	$C_{4,8}$	(0.7, 0.7625, 0.825, 0.8875)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{4,9}$	(0.4625, 0.525, 0.55, 0.6125)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{4,10}$	(0.65, 0.7125, 0.775, 0.8375)	(0.85, 0.9125, 0.975,0.9875)
	$C_{4,11}$	(0.575, 0.6375, 0.7, 0.7625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{4,12}$	(0.625, 0.6875, 0.75, 0.8125)	(0.85, 0.9125, 0.975,0.9875)
	$C_{4,13}$	(0.475, 0.5375, 0.575, 0.6375)	(0.625, 0.6875, 0.75, 0.8125)
	$C_{4,14}$	(0.8, 0.8625, 0.925, 0.9625)	(0.825, 0.8125, 0.875, 0.9375)
C_5	$C_{5,1}$	(0.75, 0.8125, 0.875, 0.9375)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{5,2}$	(0.825, 0.8875, 0.95, 0.975)	(0.85, 0.9125, 0.975,0.9875)
	$C_{5,3}$	(0.575, 0.6375, 0.7, 0.7625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{5,4}$	(0.7, 0.7625, 0.825, 0.8875)	(0.85, 0.9125, 0.975,0.9875)
	$C_{5,5}$	(0.625, 0.6875, 0.75, 0.8125)	(0.65, 0.7125, 0.775, 0.8375)
	$C_{5,6}$	(0.2625, 0.325, 0.3875, 0.45)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{5,7}$	(0.475, 0.5375, 0.575, 0.6375)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{5,8}$	(0.625, 0.6875, 0.75, 0.8125)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{5,9}$	(0.675, 0.7375, 0.8, 0.8625)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{5,10}$	(0.575, 0.6375, 0.7, 0.7625)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{5,11}$	(0.7, 0.7625, 0.825, 0.8875)	(0.85, 0.9125, 0.975,0.9875)
	$C_{5,12}$	(0.475, 0.5375, 0.575, 0.6375)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{5,13}$	(0.675, 0.7375, 0.8, 0.8625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{5,14}$	(0.825, 0.8875, 0.95, 0.975)	(0.65, 0.7125, 0.775, 0.8375)
	$C_{5,15}$	(0.475, 0.5375, 0.575, 0.6375)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{5,16}$	(0.8, 0.8625, 0.925, 0.9625)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{5,17}$	(0.6, 0.6625, 0.725, 0.7875)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{5,18}$	(0.8, 0.8625, 0.925, 0.9625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{5,19}$	(0.675, 0.7375, 0.8, 0.8625)	(0.75, 0.8125, 0.875, 0.9375)
C_6	$C_{6,1}$	(0.575, 0.6375, 0.7, 0.7625)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{6,2}$	(0.475, 0.5375, 0.575, 0.6375)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{6,3}$	(0.675, 0.7375, 0.8, 0.8625)	(0.85, 0.9125, 0.975,0.9875)
	$C_{6,4}$	(0.575, 0.6375, 0.7, 0.7625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{6,5}$	(0.7, 0.7625, 0.825, 0.8875)	(0.85, 0.9125, 0.975,0.9875)
	$C_{6,6}$	(0.7, 0.7625, 0.825, 0.8875)	(0.65, 0.7125, 0.775, 0.8375)
	$C_{6,7}$	(0.675, 0.7375, 0.8, 0.8625)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{6,8}$	(0.8, 0.8625, 0.925, 0.9625)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{6,9}$	(0.7, 0.7625, 0.825, 0.8875)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{6,10}$	(0.4625, 0.525, 0.55, 0.6125)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{6,11}$	(0.65, 0.7125, 0.775, 0.8375)	(0.85, 0.9125, 0.975,0.9875)
	$C_{6,12}$	(0.575, 0.6375, 0.7, 0.7625)	(0.65, 0.7125, 0.775, 0.8375)
	$C_{6,13}$	(0.625, 0.6875, 0.75, 0.8125)	(0.825, 0.8125, 0.875, 0.9375)
C_7	$C_{7,1}$	(0.475, 0.5375, 0.575, 0.6375)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{7,2}$	(0.625, 0.6875, 0.75, 0.8125)	(0.85, 0.9125, 0.975,0.9875)
	$C_{7,3}$	(0.575, 0.6375, 0.7, 0.7625)	(0.75, 0.8125, 0.875, 0.9375)
	$C_{7,4}$	(0.7, 0.7625, 0.825, 0.8875)	(0.85, 0.9125, 0.975,0.9875)
	$C_{7,5}$	(0.7, 0.7625, 0.825, 0.8875)	(0.825, 0.8125, 0.875, 0.9375)
	$C_{7,6}$	(0.4625, 0.525, 0.55, 0.6125)	(0.675, 0.7375, 0.800, 0.8625)
	$C_{7,7}$	(0.65, 0.7125, 0.775, 0.8375)	(0.85, 0.9125, 0.975,0.9875)
	$C_{7,8}$	(0.575, 0.6375, 0.7, 0.7625)	(0.75, 0.8125, 0.875, 0.9375)

Table 5.7: Computed ratings and aggregated weights of main-criteria (2nd Level) in terms of fuzzy numbers

1st Level	Criteria	Computed ratings	Aggregated weights
Evaluation index of potential suppliers in ASC, (C)	C_1	(0.528, 0.662, 0.834, 1.025)	(0.825, 0.812, 0.875, 0.9375)
	C_2	(0.518, 0.652, 0.819, 1.005)	(0.675, 0.7375, 0.80, 0.8625)
	C_3	(0.519, 0.650, 0.816, 1.000)	(0.85, 0.9125, 0.975,0.9875)
	C_4	(0.663, 0.676, 0.840, 0.991)	(0.75, 0.8125, 0.875, 0.9375)
	C_5	(0.526, 0.655, 0.821, 0.998)	(0.85, 0.9125, 0.975,0.9875)
	C_6	(0.520, 0.645, 0.808, 0.984)	(0.65, 0.7125, 0.775, 0.8375)
	C_7	(0.497, 0.618, 0.773, 0.944)	(0.75, 0.8125, 0.875, 0.9375)

Table 5.11: Priority weights of 1st level indices assigned by the decision-makers

1st level indices C_i	Subjective Importance Weights Given by the Decision-Makers				
	DM1	DM2	DM3	DM4	DM5
C_1	H	H	H	H	H
C_2	VH	H	VH	H	VH
C_3	FH	H	VH	VH	H
C_4	H	FH	FH	H	H
C_5	VH	H	H	H	FH
C_6	H	H	FH	H	H
C_7	H	H	H	H	H

Table 5.12: Priority weights of 2nd level sub-indices assigned by the decision-makers

2nd level sub-indices, C_{ij}	Subjective Importance Weights Given by the Decision-Makers				
	DM1	DM2	DM3	DM4	DM5
C_{11}	AH	AH	H	H	H
C_{12}	VH	VH	H	VH	H
C_{13}	FH	FH	H	H	H
C_{14}	H	H	H	VH	H
C_{15}	H	H	H	H	VH
C_{16}	AH	VH	VH	VH	AH
C_{17}	FH	H	H	H	H
C_{18}	H	VH	VH	VH	H
C_{19}	FH	FH	H	H	H
$C_{1,10}$	M	FH	FH	H	FH
$C_{1,11}$	H	VH	AH	H	H
$C_{1,12}$	H	H	H	H	VH
$C_{1,13}$	H	H	H	H	H
$C_{1,14}$	VH	VH	H	H	H
$C_{1,15}$	FH	FH	H	H	H
$C_{1,16}$	H	H	H	VH	H
$C_{1,17}$	H	H	H	H	VH
$C_{1,18}$	H	VH	H	VH	AH
$C_{1,19}$	FH	H	H	H	H
$C_{1,20}$	H	H	H	H	H
$C_{1,21}$	VH	VH	H	VH	H
$C_{1,22}$	FH	FH	H	H	H
$C_{1,23}$	H	H	H	VH	H
$C_{1,24}$	H	H	H	H	VH
$C_{1,25}$	H	VH	VH	VH	AH
$C_{1,26}$	FH	H	H	H	H
C_{21}	H	H	VH	VH	H
C_{22}	FH	FH	H	H	H
C_{23}	M	FH	FH	H	FH
C_{24}	H	VH	H	H	H
C_{25}	H	H	H	H	VH

C_{26}	AH	AH	H	H	H
C_{27}	VH	VH	H	H	H
C_{28}	H	H	H	H	H
C_{29}	VH	VH	H	VH	H
$C_{2,10}$	FH	FH	H	H	H
$C_{2,11}$	H	H	H	VH	H
$C_{2,12}$	H	H	H	H	VH
$C_{2,13}$	H	VH	H	VH	AH
$C_{2,14}$	FH	H	H	H	H
$C_{2,15}$	H	H	H	H	H
$C_{2,16}$	VH	VH	H	VH	H
$C_{2,17}$	FH	FH	H	H	H
$C_{2,18}$	H	H	H	VH	H
$C_{2,19}$	H	H	H	H	VH
$C_{2,20}$	H	VH	H	VH	AH
$C_{2,21}$	FH	H	H	H	H
$C_{2,22}$	H	H	VH	VH	H
C_{31}	FH	FH	H	H	H
C_{32}	M	FH	FH	H	FH
C_{33}	H	VH	H	H	H
C_{34}	H	H	H	H	VH
C_{35}	AH	H	H	H	H
C_{36}	VH	H	H	H	H
C_{37}	AH	VH	VH	VH	AH
C_{38}	FH	H	H	H	H
C_{39}	H	VH	VH	VH	H
$C_{3,10}$	FH	FH	H	H	H
$C_{3,11}$	M	FH	FH	H	FH
$C_{3,12}$	H	VH	AH	H	H
$C_{3,13}$	H	H	H	H	VH
$C_{3,14}$	H	H	H	H	H
C_{41}	VH	H	H	H	H
C_{42}	FH	FH	H	H	H
C_{43}	AH	VH	VH	VH	AH
C_{44}	FH	H	H	H	H
C_{45}	H	VH	H	VH	H
C_{46}	FH	FH	H	H	H
C_{47}	M	FH	FH	H	H
C_{48}	H	VH	H	H	H
C_{49}	H	H	H	H	VH
$C_{4,10}$	H	H	H	H	H
$C_{4,11}$	H	VH	H	H	H
$C_{4,12}$	H	H	H	H	VH
$C_{4,13}$	AH	VH	H	H	H
$C_{4,14}$	VH	H	H	VH	H
C_{51}	AH	VH	VH	VH	AH
C_{52}	FH	H	H	H	H
C_{53}	H	VH	VH	VH	H
C_{54}	FH	FH	H	H	H

C_{55}	M	FH	FH	H	FH
C_{56}	H	VH	AH	H	H
C_{57}	H	H	H	H	VH
C_{58}	H	H	H	H	H
C_{59}	VH	H	VH	H	H
$C_{5,10}$	FH	FH	H	H	H
$C_{5,11}$	AH	VH	VH	H	H
$C_{5,12}$	FH	H	H	H	H
$C_{5,13}$	H	VH	H	VH	H
$C_{5,14}$	FH	FH	H	H	H
$C_{5,15}$	M	FH	FH	H	H
$C_{5,16}$	H	VH	H	VH	H
$C_{5,17}$	H	H	H	VH	VH
$C_{5,18}$	H	H	H	VH	H
$C_{5,19}$	H	VH	H	H	H
C_{61}	H	H	H	H	VH
C_{62}	AH	H	H	H	H
C_{63}	VH	H	H	H	H
C_{64}	H	VH	VH	VH	AH
C_{65}	H	VH	H	H	H
C_{66}	H	H	H	H	VH
C_{67}	AH	H	H	H	H
C_{68}	VH	H	H	H	H
C_{69}	AH	VH	VH	VH	AH
$C_{6,10}$	FH	H	H	H	H
$C_{6,11}$	H	VH	VH	VH	H
$C_{6,12}$	FH	H	H	H	H
$C_{6,13}$	M	FH	FH	H	H
C_{71}	H	VH	H	H	H
C_{72}	H	H	H	H	H
C_{73}	H	H	H	H	H
C_{74}	VH	H	H	H	H
C_{75}	FH	FH	H	H	H
C_{76}	AH	VH	VH	VH	H
C_{77}	FH	H	H	H	H
C_{78}	H	VH	H	VH	VH

Table 5.13: Performance ratings of 2^{nd} level sub-indices assigned by the decision-makers **(Alternative 1)**

2^{nd} level sub-indices	Subjective Rating Given by the Decision-Makers				
C_{ij}	DM1	DM2	DM3	DM4	DM5
C_{11}	VI	VI	AI	VI	VI
C_{12}	VI	VI	VI	VI	VI
C_{13}	S	S	FS	S	FS
C_{14}	M	FS	M	FS	FS
C_{15}	M	M	M	M	M
C_{16}	FP	FP	M	M	M
C_{17}	S	S	S	VI	VI
C_{18}	M	M	M	M	FS
C_{19}	VI	VI	S	FS	FS
$C_{1,10}$	M	M	M	FP	FP
$C_{1,11}$	P	P	FP	P	P
$C_{1,12}$	FS	FS	FS	FS	FS
$C_{1,13}$	S	S	S	FS	S
$C_{1,14}$	VI	S	VI	VI	VI
$C_{1,15}$	VI	VI	VI	VI	VI
$C_{1,16}$	S	S	FS	S	FS
$C_{1,17}$	M	FS	M	FS	FS
$C_{1,18}$	M	M	FS	M	M
$C_{1,19}$	FP	FP	M	M	M
$C_{1,20}$	S	S	FS	VI	VI
$C_{1,21}$	M	M	M	M	FS
$C_{1,22}$	VI	VI	S	FS	FS
$C_{1,23}$	M	M	M	FP	FP
$C_{1,24}$	P	P	M	P	M
$C_{1,25}$	FS	FS	FS	FS	FS
$C_{1,26}$	S	FS	S	FS	S
C_{21}	VI	VI	AI	VI	VI
C_{22}	S	VI	VI	VI	VI
C_{23}	M	M	M	M	M
C_{24}	FP	FP	M	M	M
C_{25}	S	S	S	VI	VI

C_{26}	M	M	M	M	FS
C_{27}	VI	VI	S	FS	FS
C_{28}	M	M	M	FP	FP
C_{29}	P	FP	FP	P	P
$C_{2,10}$	FS	FS	FS	FS	FS
$C_{2,11}$	S	FS	S	FS	S
$C_{2,12}$	VI	S	VI	VI	VI
$C_{2,13}$	VI	S	VI	S	S
$C_{2,14}$	S	S	FS	S	FS
$C_{2,15}$	M	FS	M	FS	FS
$C_{2,16}$	M	M	FS	M	M
$C_{2,17}$	P	FP	M	M	M
$C_{2,18}$	M	M	M	M	M
$C_{2,19}$	FP	FP	M	M	FP
$C_{2,20}$	VI	VI	AI	VI	VI
$C_{2,21}$	VI	VI	VI	VI	VI
$C_{2,22}$	S	S	FS	S	FS
C_{31}	M	S	M	FS	FS
C_{32}	M	M	M	M	M
C_{33}	FP	FP	M	M	M
C_{34}	S	S	S	S	VI
C_{35}	M	M	M	M	FS
C_{36}	VI	VI	S	FS	FS
C_{37}	M	M	M	FP	FP
C_{38}	P	P	FP	P	P
C_{39}	FS	FS	FS	FS	FS
$C_{3,10}$	FS	S	S	FS	S
$C_{3,11}$	VI	S	VI	VI	VI
$C_{3,12}$	S	S	S	S	S
$C_{3,13}$	M	M	M	M	FS
$C_{3,14}$	VI	VI	S	FS	FS
C_{41}	M	M	M	FP	FP
C_{42}	P	FP	FP	P	P
C_{43}	FS	FS	S	FS	FS
C_{44}	S	FS	S	FS	S
C_{45}	VI	S	VI	VI	VI

C_{46}	VI	S	VI	S	S
C_{47}	S	S	FS	S	FS
C_{48}	M	FS	M	FS	FS
C_{49}	M	M	FS	M	M
$C_{4,10}$	P	FP	FP	M	M
$C_{4,11}$	M	M	M	M	M
$C_{4,12}$	FP	FP	M	M	FP
$C_{4,13}$	VI	VI	AI	VI	VI
$C_{4,14}$	VI	S	S	VI	VI
C_{51}	S	S	FS	S	FS
C_{52}	M	S	M	FS	FS
C_{53}	M	M	M	M	M
C_{54}	FP	FP	M	M	M
C_{55}	S	S	S	S	S
C_{56}	VI	S	VI	VI	VI
C_{57}	S	S	S	S	S
C_{58}	M	M	M	M	FS
C_{59}	VI	VI	S	FS	FS
$C_{5,10}$	M	M	M	FP	FP
$C_{5,11}$	P	FP	FP	P	P
$C_{5,12}$	FS	FS	S	FS	FS
$C_{5,13}$	S	FS	S	FS	S
$C_{5,14}$	VI	S	S	S	VI
$C_{5,15}$	VI	S	VI	S	S
$C_{5,16}$	S	S	FS	S	FS
$C_{5,17}$	P	FP	FP	P	P
$C_{5,18}$	FS	FS	S	FS	FS
$C_{5,19}$	S	FS	S	FS	S
C_{61}	VI	S	VI	VI	VI
C_{62}	VI	S	VI	S	S
C_{63}	S	S	FS	S	FS
C_{64}	M	FS	M	FS	FS
C_{65}	M	M	FS	M	M
C_{66}	P	FP	P	FS	M
C_{67}	M	M	M	M	M
C_{68}	FP	FP	M	M	FP

C_{69}	VI	VI	AI	VI	VI
$C_{6,10}$	VI	S	FS	S	S
$C_{6,11}$	S	FS	FS	FS	FS
$C_{6,12}$	M	S	M	FS	FS
$C_{6,13}$	M	M	M	M	M
C_{71}	FP	FP	M	M	M
C_{72}	S	S	S	S	S
C_{73}	VI	S	VI	VI	VI
C_{74}	S	S	S	S	S
C_{75}	M	M	M	M	FS
C_{76}	P	FP	FP	P	P
C_{77}	FS	FS	FS	FS	FS
C_{78}	S	S	FS	FS	S

Table 5.14: Performance ratings of 2nd level sub-indices assigned by the decision-makers **(Alternative 2)**

2nd level sub-indices C_{ij}	Subjective Rating Given by the Decision-Makers				
	DM1	DM2	DM3	DM4	DM5
C_{11}	AI	AI	VI	VI	VI
C_{12}	S	VI	VI	S	S
C_{13}	FS	FS	FS	FS	FS
C_{14}	S	S	VI	S	S
C_{15}	M	M	M	FP	M
C_{16}	S	VI	S	VI	VI
C_{17}	AI	VI	VI	VI	VI
C_{18}	S	S	S	S	S
C_{19}	FS	S	S	S	S
$C_{1,10}$	AI	AI	VI	VI	VI
$C_{1,11}$	S	VI	VI	S	S
$C_{1,12}$	FS	FS	S	FS	FS
$C_{1,13}$	S	S	VI	S	S
$C_{1,14}$	M	M	M	FP	M
$C_{1,15}$	S	VI	S	VI	VI
$C_{1,16}$	AI	VI	AI	VI	VI
$C_{1,17}$	S	S	FS	S	S
$C_{1,18}$	FS	S	S	S	S
$C_{1,19}$	AI	AI	AI	VI	VI
$C_{1,20}$	FS	FS	FS	FS	FS
$C_{1,21}$	S	S	VI	S	S
$C_{1,22}$	M	M	M	FP	M
$C_{1,23}$	S	VI	S	VI	VI
$C_{1,24}$	AI	VI	S	VI	VI
$C_{1,25}$	S	S	S	S	S
$C_{1,26}$	FS	S	S	S	S
C_{21}	VI	VI	VI	VI	S
C_{22}	S	VI	VI	S	S
C_{23}	M	M	M	FP	M
C_{24}	S	VI	S	VI	VI
C_{25}	AI	VI	VI	VI	VI
C_{26}	S	S	S	S	S

C_{27}	FS	S	S	S	S
C_{28}	AI	AI	VI	VI	VI
C_{29}	S	VI	VI	S	S
$C_{2,10}$	FS	FS	S	FS	FS
$C_{2,11}$	S	S	VI	S	S
$C_{2,12}$	M	M	M	FP	M
$C_{2,13}$	S	VI	S	VI	VI
$C_{2,14}$	AI	VI	AI	VI	VI
$C_{2,15}$	S	S	FS	S	S
$C_{2,16}$	FS	S	S	S	S
$C_{2,17}$	AI	AI	AI	VI	VI
$C_{2,18}$	FS	FS	S	S	FS
$C_{2,19}$	S	S	VI	S	S
$C_{2,20}$	M	M	M	P	M
$C_{2,21}$	M	M	M	FP	M
$C_{2,22}$	S	VI	S	VI	VI
C_{31}	AI	VI	VI	VI	VI
C_{32}	S	S	S	S	S
C_{33}	FS	S	S	S	S
C_{34}	AI	AI	VI	VI	VI
C_{35}	S	VI	VI	S	S
C_{36}	FS	FS	S	FS	FS
C_{37}	S	S	VI	S	S
C_{38}	M	M	M	FP	M
C_{39}	S	VI	S	VI	VI
$C_{3,10}$	AI	VI	AI	VI	VI
$C_{3,11}$	S	S	FS	S	S
$C_{3,12}$	FS	S	S	S	S
$C_{3,13}$	S	S	VI	S	S
$C_{3,14}$	M	M	M	FP	M
C_{41}	S	VI	S	VI	VI
C_{42}	AI	VI	AI	VI	VI
C_{43}	S	S	FS	S	S
C_{44}	FS	S	S	S	S
C_{45}	AI	AI	AI	VI	VI
C_{46}	FS	FS	FS	FS	FS

C_{47}	S	S	VI	S	S
C_{48}	M	M	M	FP	M
C_{49}	S	VI	S	VI	VI
$C_{4,10}$	AI	VI	S	VI	VI
$C_{4,11}$	S	S	S	S	S
$C_{4,12}$	FS	S	S	S	S
$C_{4,13}$	VI	VI	VI	VI	S
$C_{4,14}$	S	VI	VI	S	S
C_{51}	M	M	M	FP	M
C_{52}	S	VI	S	VI	VI
C_{53}	AI	VI	VI	VI	VI
C_{54}	S	S	S	S	S
C_{55}	FS	S	S	S	S
C_{56}	AI	AI	VI	VI	VI
C_{57}	S	VI	VI	S	S
C_{58}	FS	FS	FS	FS	FS
C_{59}	S	S	VI	S	S
$C_{5,10}$	M	M	M	FP	M
$C_{5,11}$	S	VI	S	VI	VI
$C_{5,12}$	AI	VI	VI	VI	VI
$C_{5,13}$	S	S	S	S	S
$C_{5,14}$	FS	S	S	S	S
$C_{5,15}$	AI	AI	VI	VI	VI
$C_{5,16}$	S	VI	VI	S	S
$C_{5,17}$	FS	FS	S	FS	FS
$C_{5,18}$	S	S	VI	S	S
$C_{5,19}$	M	M	M	FP	M
C_{61}	S	VI	S	VI	VI
C_{62}	AI	VI	AI	VI	VI
C_{63}	S	S	FS	S	S
C_{64}	FS	S	S	S	S
C_{65}	AI	AI	AI	VI	VI
C_{66}	FS	FS	FS	FS	FS
C_{67}	S	S	VI	S	S
C_{68}	M	M	M	FP	M
C_{69}	S	VI	S	VI	VI

$C_{6,10}$	AI	AI	VI	VI	VI
$C_{6,11}$	S	VI	VI	S	S
$C_{6,12}$	FS	FS	FS	FS	FS
$C_{6,13}$	S	S	VI	S	S
C_{71}	M	M	M	FP	M
C_{72}	S	VI	S	VI	VI
C_{73}	AI	VI	VI	VI	VI
C_{74}	S	S	S	S	S
C_{75}	FS	S	S	S	S
C_{76}	AI	AI	VI	VI	VI
C_{77}	S	VI	VI	S	FS
C_{78}	FS	S	S	FS	FS

Table 5.15: Performance ratings of 2^{nd} level sub-indices assigned by the decision-makers **(Alternative 3)**

2^{nd} level sub-indices C_{ij}	Subjective Rating Given by the Decision-Makers				
	DM1	DM2	DM3	DM4	DM5
C_{11}	VP	P	FP	FP	FP
C_{12}	P	P	P	P	P
C_{13}	FP	P	FP	P	P
C_{14}	M	M	M	M	M
C_{15}	M	FS	FS	M	M
C_{16}	M	FP	FP	FP	FP
C_{17}	P	P	P	VP	P
C_{18}	M	FS	S	M	M
C_{19}	M	M	M	M	M
$C_{1,10}$	P	P	FP	P	P
$C_{1,11}$	FP	FP	P	P	P
$C_{1,12}$	M	VP	P	FP	FP
$C_{1,13}$	FS	P	P	P	P
$C_{1,14}$	M	M	M	M	M
$C_{1,15}$	FS	FS	M	M	FS
$C_{1,16}$	FP	FP	FP	FP	FP
$C_{1,17}$	P	P	VP	P	P
$C_{1,18}$	FS	S	M	M	FS
$C_{1,19}$	M	M	M	M	M
$C_{1,20}$	P	FP	P	P	P
$C_{1,21}$	FP	P	P	P	FP
$C_{1,22}$	VP	P	FP	FP	VP
$C_{1,23}$	P	P	P	P	P
$C_{1,24}$	FP	P	FP	P	FP
$C_{1,25}$	M	M	M	M	M
$C_{1,26}$	FS	FS	M	M	FS
C_{21}	FP	FP	FP	FP	FP
C_{22}	P	P	VP	P	P
C_{23}	FS	S	M	M	FS
C_{24}	M	M	M	M	M
C_{25}	P	FP	P	P	P
C_{26}	FP	P	P	P	FP

C_{27}	VP	P	FP	FP	VP
C_{28}	P	P	P	P	P
C_{29}	FP	P	FP	P	FP
$C_{2,10}$	M	M	M	M	M
$C_{2,11}$	FS	FS	M	M	FS
$C_{2,12}$	FP	FP	FP	FP	FP
$C_{2,13}$	P	P	VP	P	P
$C_{2,14}$	FS	S	M	M	FS
$C_{2,15}$	M	M	M	M	M
$C_{2,16}$	FP	FP	P	FP	P
$C_{2,17}$	P	M	M	M	M
$C_{2,18}$	FS	M	FS	FS	M
$C_{2,19}$	M	M	FP	FP	FP
$C_{2,20}$	P	P	P	P	VP
$C_{2,21}$	FP	M	FS	S	M
$C_{2,22}$	VP	M	M	M	M
C_{31}	P	P	P	FP	P
C_{32}	FP	FP	FP	P	P
C_{33}	P	M	VP	P	FP
C_{34}	FS	FS	P	P	P
C_{35}	M	M	M	M	M
C_{36}	P	FS	FS	M	M
C_{37}	FP	FP	FP	FP	FP
C_{38}	M	M	M	M	M
C_{39}	FS	FS	M	M	FS
$C_{3,10}$	FP	FP	FP	FP	FP
$C_{3,11}$	P	P	VP	P	P
$C_{3,12}$	FS	S	M	M	FS
$C_{3,13}$	FP	P	FP	P	FP
$C_{3,14}$	M	M	M	M	P
C_{41}	M	FS	FS	M	FS
C_{42}	M	FP	FP	FP	M
C_{43}	P	P	P	VP	P
C_{44}	M	FS	S	M	FP
C_{45}	M	M	M	M	VP
C_{46}	P	P	FP	P	P

C_{47}	M	M	M	M	M
C_{48}	FS	FS	M	M	FS
C_{49}	FP	FP	FP	FP	FP
$C_{4,10}$	P	P	VP	P	P
$C_{4,11}$	FS	S	M	M	FS
$C_{4,12}$	M	M	M	M	M
$C_{4,13}$	P	FP	P	P	P
$C_{4,14}$	FP	P	P	P	FP
C_{51}	VP	P	FP	FP	VP
C_{52}	P	P	P	P	P
C_{53}	FP	P	FP	P	FP
C_{54}	M	M	M	M	M
C_{55}	FS	FS	M	M	FS
C_{56}	FP	P	FP	P	P
C_{57}	M	FP	M	M	M
C_{58}	M	FS	FS	M	M
C_{59}	M	FP	FP	FP	FP
$C_{5,10}$	P	P	P	VP	P
$C_{5,11}$	M	FS	S	M	M
$C_{5,12}$	M	M	M	M	M
$C_{5,13}$	P	P	P	P	P
$C_{5,14}$	FP	FP	P	P	P
$C_{5,15}$	M	VP	P	FP	FP
$C_{5,16}$	FS	P	P	P	P
$C_{5,17}$	M	M	M	M	M
$C_{5,18}$	FS	FS	M	M	FS
$C_{5,19}$	FP	FP	FP	FP	FP
C_{61}	P	P	VP	P	P
C_{62}	FS	S	M	M	FS
C_{63}	M	FS	M	M	M
C_{64}	P	FP	P	P	P
C_{65}	FP	P	P	P	FP
C_{66}	VP	P	FP	FP	VP
C_{67}	P	P	P	P	P
C_{68}	FP	P	FP	P	FP
C_{69}	M	M	M	M	M

$C_{6,10}$	FP	FP	P	FP	FP
$C_{6,11}$	P	P	VP	P	P
$C_{6,12}$	FS	S	M	M	FS
$C_{6,13}$	M	M	M	M	M
C_{71}	P	FP	P	P	P
C_{72}	FP	P	P	P	FP
C_{73}	VP	P	FP	P	P
C_{74}	P	P	P	P	P
C_{75}	FP	FP	FP	FP	P
C_{76}	P	P	VP	P	P
C_{77}	FS	S	M	M	FS
C_{78}	M	M	M	M	FS

Table 5.16: Performance ratings and weights of 2nd Level sub-indices assigned by the decision-makers **(Alternative 1)**

2nd level sub-indices, C_{ij}	Aggregated fuzzy appropriateness rating,(U_{ij})	Aggregated fuzzy priority weight,(W_{ij})
C_{11}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.870,0.889,0.931,0.945;0.500),(0.832,0.868,0.952,0.982;1.000)]
C_{12}	[(0.948,0.985,0.993,0.993;0.500),(0.930,0.980,1.000,1.000;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{13}	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{14}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{15}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{16}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{17}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{18}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{19}	[(0.796,0.826,0.877,0.895;0.500),(0.748,0.800,0.904,0.938;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,10}$	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
$C_{1,11}$	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{1,12}$	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,13}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{1,14}$	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{1,15}$	[(0.948,0.985,0.993,0.993;0.500),(0.930,0.980,1.000,1.000;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,16}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,17}$	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,18}$	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{1,19}$	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{1,20}$	[(0.822,0.855,0.903,0.918;0.500),(0.776,0.830,0.928,0.960;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{1,21}$	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{1,22}$	[(0.796,0.826,0.877,0.895;0.500),(0.748,0.800,0.904,0.938;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,23}$	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,24}$	[(0.214,0.253,0.311,0.337;0.500),(0.152,0.224,0.340,0.398;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,25}$	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
$C_{1,26}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{21}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{22}	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{23}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{24}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{25}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{26}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.870,0.889,0.931,0.945;0.500),(0.832,0.868,0.952,0.982;1.000)]
C_{27}	[(0.796,0.826,0.877,0.895;0.500),(0.748,0.800,0.904,0.938;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{28}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{29}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{2,10}$	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{2,11}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,12}$	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]

$C_{2,13}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{2,14}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{2,15}$	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{2,16}$	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{2,17}$	[(0.306,0.347,0.420,0.449;0.500),(0.234,0.310,0.456,0.520;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{2,18}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,19}$	[(0.301,0.334,0.410,0.442;0.500),(0.230,0.296,0.448,0.512;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,20}$	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{2,21}$	[(0.948,0.985,0.993,0.993;0.500),(0.930,0.980,1.000,1.000;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{2,22}$	[(0.730,0.758,0.834,0.861;0.500)(0.664,0.720,0.872,0.926;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{31}	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{32}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{33}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{34}	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{35}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{36}	[(0.796,0.826,0.877,0.895;0.500),(0.748,0.800,0.904,0.938;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{37}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{38}	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{39}	[(0.650,0.6730.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{3,10}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{3,11}$	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
$C_{3,12}$	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{3,13}$	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{3,14}$	[(0.796,0.826,0.877,0.895;0.500),(0.748,0.800,0.904,0.938;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{41}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{42}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{43}	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{44}	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{45}	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{46}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{47}	[(0.7300.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
C_{48}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{49}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,10}$	[(0.272,0.307,0.377,0.407;0.500),(0.204,0.272,0.412,0.474;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{4,11}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,12}$	[(0.301,0.334,0.410,0.442;0.500),(0.230,0.296,0.448,0.512;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,13}$	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{4,14}$	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{51}	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{52}	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{53}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{54}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{55}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{56}	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]

C_{57}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{58}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{59}	[(0.796,0.826,0.877,0.895;0.500),(0.748,0.800,0.904,0.938;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,10}$	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{5,11}$	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{5,12}$	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{5,13}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,14}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{5,15}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
$C_{5,16}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,17}$	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,18}$	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{5,19}$	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{61}	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{62}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{63}	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{64}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{65}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{66}	[(0.292,0.324,0.388,0.416;0.500),(0.230,0.292,0.420,0.478;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{67}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{68}	[(0.301,0.334,0.410,0.442;0.500),(0.230,0.296,0.448,0.512;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{69}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
$C_{6,10}$	[(0.789,0.821,0.881,0.901;0.500),(0.734,0.790,0.912,0.954;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{6,11}$	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{6,12}$	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{6,13}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
C_{71}	[(0.335,0.374,0.453,0.484;0.500),(0.260,0.334,0.492,0.558;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{72}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{73}	[(0.9150,951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{74}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{75}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{76}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{77}	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{78}	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]

Table 5.17: Performance ratings and weights of 2nd level sub-indices assigned by the decision-makers **(Alternative 2)**

2nd level sub-indices, C_{ij}	Aggregated fuzzy appropriateness rating,(U_{ij})	Aggregated fuzzy priority weight,(W_{ij})
C_{11}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.870,0.889,0.931,0.945;0.500),(0.832,0.868,0.952,0.982;1.000)]
C_{12}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{13}	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{14}	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{15}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{16}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{17}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{18}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{19}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,10}$	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.0001.000;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
$C_{1,11}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{1,12}$	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,13}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{1,14}$	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{1,15}$	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,16}$	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.0001.000;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,17}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,18}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{1,19}$	[(0.979,0.994,0.997,0.997;0.500),(0.972,0.992,1.000,1.000;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{1,20}$	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{1,21}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{1,23}$	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,24}$	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,25}$	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
$C_{1,26}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{21}	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{22}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{23}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{24}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{25}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{26}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.870,0.889,0.931,0.945;0.500),(0.832,0.868,0.952,0.982;1.000)]
C_{27}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{28}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{29}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{2,10}$	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{2,11}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,12}$	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]

$C_{2,13}$	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{2,14}$	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{2,15}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{2,16}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{2,17}$	[(0.979,0.994,0.997,0.997;0.500),(0.972,0.992,1.000,1.000;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{2,18}$	[(0.703,0.730,0.800,0.837;0.500),(0.636,0.690,0.848,0.904;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,19}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,20}$	[(0.340,0.386,0.462,0.491;0.500),(0.264,0.348,0.500,0.566;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{2,21}$	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{2,22}$	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{31}	[(0.958,0.988,0.994,0.994;0.500),(0.9440.984,1.000,1.000;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{32}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{33}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{34}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{35}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{37}	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{38}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{39}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{3,10}$	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{3,11}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{3,12}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
$C_{3,13}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{3,14}$	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{41}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{42}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{43}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{44}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{45}	[(0.979,0.994,0.997,0.997;0.500),(0.972,0.992,1.000,1.000;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{46}	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{47}	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{48}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
C_{49}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,10}$	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,11}$	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{4,12}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,13}$	[(0.915,0.951,0.971,0.976;0.500),(0.888,0.940,0.984,0.994;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,14}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
C_{51}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{52}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{53}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{54}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{55}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{56}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.9881.000,1.000;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{57}	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]

C_{58}	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{59}	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{5,10}$	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,11}$	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{5,12}$	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{5,13}$	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{5,14}$	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,15}$	[(0.969,0.991,0.996,0.996;0.500),(0.9580.988,1.000,1.000;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{5,16}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
$C_{5,17}$	[(0.677,0.701,0.783,0.814;0.500),(0.608,0.660,0.824,0.882;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,18}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,19}$	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{61}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{62}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{63}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{64}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{65}	[(0.979,0.994,0.997,0.997;0.500),(0.972,0.992,1.000,1.000;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{66}	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{67}	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{68}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{69}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{6,10}$	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
$C_{6,11}$	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{6,12}$	[(0.650,0.673,0.758,0.790;0.500),(0.580,0.630,0.800,0.860;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{6,13}$	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{71}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
C_{72}	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{73}	[(0.958,0.988,0.994,0.994;0.500),(0.944,0.984,1.000,1.000;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{74}	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{75}	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{76}	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{77}	[(0.822,0.855,0.903,0.918;0.500),(0.776,0.830,0.928,0.960;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{78}	[(0.703,0.730,0.809,0.837;0.500),(0.636,0.690,0.848,0.904;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]

Table 5.18: Performance ratings and weights of 2nd level sub-indices assigned by the decision-makers **(Alternative 3)**

2nd level sub-indices, C_{ij}	Aggregated fuzzy appropriateness rating,(U_{ij})	Aggregated fuzzy priority weight,(W_{ij})
C_{11}	[(0.159,0.179,0.230,0.262;0.500),(0.110,0.152,0.256,0.312;1.000)]	[(0.870,0.889,0.931,0.945;0.500),(0.832,0.868,0.952,0.982;1.000)]
C_{12}	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{13}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{14}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{15}	[(0.502,0.541,0.626,0.657;0.500),(0.424,0.498,0.668,0.734;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{16}	[(0.267,0.295,0.368,0.400;0.500),(0.200,0.258,0.404,0.466;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{17}	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{18}	[(0.528,0.569,0.651,0.680;0.500),(0.452,0.528,0.692,0.756;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{19}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,10}$	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
$C_{1,11}$	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{1,12}$	[(0.193,0.218,0.273,0.304;0.500),(0.140,0.190,0.300,0.358;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,13}$	[(0.200,0.231,0.280,0.304;0.500),(0.148,0.206,0.304,0.356;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{1,14}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{1,15}$	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,16}$	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.220,0.360,0.420;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,17}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,18}$	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{1,19}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{1,20}$	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{1,21}$	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{1,22}$	[(0.114,0.129,0.168,0.201;0.500),(0.076,0.108,0.188,0.242;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{1,23}$	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,24}$	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{1,25}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{21}	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.220,0.360,0.420;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{22}	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{23}	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{24}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{25}	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{26}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.870,0.889,0.931,0.945;0.500),(0.832,0.868,0.952,0.982;1.000)]
C_{27}	[(0.114,0.129,0.168,0.201;0.500),(0.076,0.108,0.188,0.242;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{28}	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{29}	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{2,10}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{2,11}$	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,12}$	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.220,0.360,0.420;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,13}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{2,14}$	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]

$C_{2,15}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{2,16}$	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{2,17}$	[(0.340,0.386,0.462,0.491;0.500),(0.264,0.348,0.500,0.566;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{2,18}$	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,19}$	[(0.301,0.334,0.410,0.442;0.500),(0.230,0.296,0.448,0.512;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{2,20}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{2,21}$	[(0.494,0.530,0.609,0.638;0.500),(0.422,0.490,0.648,0.710;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{2,22}$	[(0.324,0.364,0.433,0.465;0.500),(0.256,0.328,0.468,0.534;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{31}	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{32}	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{33}	[(0.164,0.191,0.240,0.269;0.500),(0.114,0.166,0.264,0.320;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{34}	[(0.313,0.341,0.399,0.426;0.500),(0.256,0.312,0.4280.482;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{35}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{36}	[(0.439,0.474,0.550,0.580;0.500),(0.368,0.436,0.588,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{37}	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.220,0.360,0.420;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{38}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{39}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{3,10}$	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.2200.360,0.420;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{3,11}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
$C_{3,12}$	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{3,13}$	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{3,14}$	[(0.340,0.386,0.462,0.491;0.500),(0.264,0.348,0.500,0.566;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{41}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{42}	[(0.301,0.334,0.410,0.442;0.500),(0.230,0.296,0.448,0.512;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{43}	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{44}	[(0.494,0.530,0.609,0.638;0.500),(0.422,0.490,0.648,0.710;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{45}	[(0.324,0.364,0.433,0.465;0.500),(0.256,0.328,0.468,0.534;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{46}	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{47}	[(0.403,0.4530.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
C_{48}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{49}	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.220,0.360,0.420;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,10}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
$C_{4,11}$	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,12}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{4,13}$	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
$C_{4,14}$	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
C_{51}	[(0.114,0.129,0.168,0.201;0.500),(0.076,0.108,0.188,0.242;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
C_{52}	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{53}	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
C_{54}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{55}	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.627,0.657,0.739,0.769;0.500),(0.556,0.616,0.780,0.840;1.000)]
C_{56}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.859,0.886,0.930,0.943;0.500),(0.818,0.864,0.952,0.982;1.000)]
C_{57}	[(0.369,0.413,0.495,0.526;0.500),(0.290,0.372,0.536,0.604;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{58}	[(0.502,0.541,0.626,0.657;0.500),(0.424,0.498,0.668,0.734;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]

C_{59}	[(0.267,0.295,0.368,0.400;0.500),(0.200,0.258,0.404,0.466;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,10}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{5,11}$	[(0.528,0.569,0.651,0.680;0.500),(0.452,0.528,0.692,0.756;1.000)]	[(0.892,0.920,0.951,0.960;0.500),(0.860,0.904,0.968,0.988;1.000)]
$C_{5,13}$	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,14}$	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
$C_{5,15}$	[(0.193,0.218,0.273,0.304;0.500),(0.140,0.190,0.300,0.358;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
$C_{5,16}$	[(0.200,0.231,0.280,0.304;0.500),(0.148,0.206,0.304,0.356;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,17}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.849,0.883,0.928,0.942;0.500),(0.804,0.860,0.952,0.982;1.000)]
$C_{5,18}$	[(0.551,0.585,0.670,0.701;0.500),(0.476,0.542,0.712,0.776;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
$C_{5,19}$	[(0.233,0.255,0.325,0.358;0.500),(0.170,0.220,0.360,0.420;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{61}	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{62}	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{63}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{64}	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{65}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{66}	[(0.114,0.129,0.168,0.201;0.500),(0.076,0.108,0.188,0.242;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{67}	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.826,0.852,0.908,0.926;0.500),(0.776,0.824,0.936,0.976;1.000)]
C_{68}	[(0.175,0.201,0.259,0.288;0.500),(0.118,0.172,0.288,0.344;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{69}	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.969,0.991,0.996,0.996;0.500),(0.958,0.988,1.000,1.000;1.000)]
$C_{6,10}$	[(0.204,0.228,0.292,0.323;0.500),(0.144,0.196,0.324,0.382;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{6,11}$	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]
$C_{6,12}$	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
$C_{6,13}$	[(0.403,0.453,0.538,0.568;0.500),(0.320,0.410,0.580,0.650;1.000)]	[(0.654,0.686,0.765,0.793;0.500),(0.584,0.646,0.804,0.862;1.000)]
C_{71}	[(0.117,0.147,0.193,0.218;0.500),(0.066,0.124,0.216,0.268;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{72}	[(0.146,0.174,0.226,0.253;0.500),(0.092,0.148,0.252,0.306;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{73}	[(0.101,0.125,0.164,0.192;0.500),(0.058,0.104,0.184,0.236;1.000)]	[(0.783,0.815,0.885,0.908;0.500),(0.720,0.780,0.920,0.970;1.000)]
C_{74}	[(0.088,0.120,0.160,0.183;0.500),(0.040,0.100,0.180,0.230;1.000)]	[(0.816,0.849,0.907,0.925;0.500),(0.762,0.820,0.936,0.976;1.000)]
C_{75}	[(0.204,0.228,0.292,0.323;0.500),(0.144,0.196,0.324,0.382;1.000)]	[(0.730,0.758,0.834,0.861;0.500),(0.664,0.720,0.872,0.926;1.000)]
C_{76}	[(0.072,0.098,0.131,0.157;0.500),(0.032,0.080,0.148,0.198;1.000)]	[(0.925,0.954,0.973,0.977;0.500),(0.902,0.944,0.984,0.994;1.000)]
C_{77}	[(0.578,0.613,0.695,0.725;0.500),(0.504,0.572,0.736,0.798;1.000)]	[(0.756,0.787,0.860,0.884;0.500),(0.692,0.750,0.896,0.948;1.000)]
C_{78}	[(0.452,0.497,0.582,0.612;0.500),(0.372,0.454,0.624,0.692;1.000)]	[(0.882,0.917,0.950,0.959;0.500),(0.846,0.900,0.968,0.988;1.000)]